Design and Development of a Semi-automatic handloom

Thesis submitted in partial fulfilment of the requirement for the award of the Degree of

Doctor of Philosophy

By

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October 2022

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Guwahati- 781039, INDIA
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CERTIFICATE

This is to certify that the work contained in this thesis entitled **'Design Development of a Semi-automatic handloom'** submitted by Mr. Manohar Mahato to the Indian Institute of Technology Guwahati, Assam (India) for the award of the degree of Doctor of Philosophy has been carried out under my supervision. This work has not been submitted elsewhere for the award of any other degree or diploma.

Place: Guwahati
Date: 10 October 2022

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DECLARATION

I hereby declare that the work contained in this thesis entitled **'Design and Development of a Semi-automatic handloom'** is my own work done under the supervision of Prof. Amarendra Kumar Das, at the Department of Design, Indian Institute of Technology Guwahati (IITG), Assam. I hereby declare that to the best of my knowledge, it contains no materials previously published or written by another person, or substantial proportion of material which have been accepted for the award of any other degree or diploma at IITG or any other educational institute, except where due acknowledgement is made in this thesis. Any contribution made to the research made by others, with whom I have worked at IITG or elsewhere, is explicitly acknowledged in the thesis. I also hereby declare that the intellectual content of the thesis is the product of my work, and as per general norms of the reporting research findings, due acknowledgements have been made wherever the research findings of other researchers have been cited in the thesis.

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DEDICATION

I would like to dedicate this thesis to my family members and people who are working in handloom clusters across India.

ACKNOWLEDGEMENT

There are many people who have directly or indirectly contributed to the completion of this research. Before presenting this work in the conscious circle, I would like to take the opportunity to humbly and solemnly acknowledge all of them for their constant support and guidance.

First and foremost, I would like to thank my supervisor Prof. Amarendra Kumar Das, Department of Design, Indian Institute of Technology Guwahati for his guidance and intellectual inputs throughout the completion of this research. He showed tremendous confidence in me and was very patient, for which I shall always be indebted to him. I appreciated all his contributions of time, and ideas to make my doctoral experience productive and stimulating. I also thank the other members of my doctoral committee: Prof. Ravi Mokashi Punekar, Dr. Pratul Chandra Kalita, Dr. Sharmistha Banerjee, and Dr. Supradip Das from Department of Design, Dr. Karuna Kalita, and Prof. Debabrata Chakraborty from Department of Mechanical Engineering, Prof. J. Ramkumar from Department of Design, IIT Kanpur for their time, interest, and helpful comments. They had provided their valuable advice, guidance, and suggestions which helped me to undertake the research during the entire research period successfully.

I am especially grateful to my mentor Dr. Sujit Bhattacharya, Chief Scientist & Prof. ACSIR at Council of Scientific and Industrial Research - National Institute of Science, Technology and Development Studies (CSIR-NISTADS) internship in 2020, Dr. Dalgobind Mahto, Director - Professor, Jaipur, Engineering College, Kukas, Jaipur, Rajasthan, Dr. Sachindra Mahto, Professor, North Eastern Regional Institute of Science and Technology (NERIST), Arunachal Pradesh, Prof. Mangal C Mahato, North Eastern Regional Hill University, Shillong, Meghalaya, my mentor Prof. Carl Michael Johannesson, KTH, Stockholm, Sweden during TEDMINT 2017 workshop in Campus Värnamo, sponsored by 3M Svenska AB, and MECHATON 2018 workshop at Shami Shamoon College for Engineering, Beer Sheva Israel for project of Sodastream (a PepsiCo company), Kfar Saba, Israel.

My sincere thanks to Mr. Dipak Bharali from Sualkuchi Assam, Mr. Dharmendra Sarma, Guwahati, Assam, Mr. Dipankar Das from Assam Apex Weavers and Artisans Cooperative Federation (ARTFED) for their help and guidance during various phases of the research work.

I am sincerely thankful to all the faculty and staff members of Department of Design, IIT Guwahati who had helped me in whatever way they could.

I like to extend my appreciation and gratitude to Harendra Das, employee of Dipon Design Pvt. Ltd., a IIT Guwahati start-up; Bijoy Deka, Jr. Technical Superintendent, Manashjyoti Nath, Jr. Technical Superintendent, Shajumon M. S., Jr. Technical Officer, Jayanta Deka, Technical Superintendent, Dhruba Jyoti Borah, Jr. Technician, and other workshop staffs of Department of Design, IIT Guwahati, for undeviating support without which this research would have not been pursued.

My friends at Department of Design, IIT Guwahati, have contributed immensely in the completion of this research. My special thanks to Dr. Dipanka Boruah, Dr. Sachin Shivaji Jadhav, Angelus Khoh, Anusmita Das, Ummi Hani, Kelifa Seid, Basheer AA, Kankana Narayan Dev, Gurdeep Singh, Abhijit Kakati, Dr. Mohammad Shahid, Dr. Subhajit Chandra, and Anjali Narzari, for suggestions, co-operation, and support they extended during my research at IIT Guwahati to make it a memorable experience.

And finally, I am grateful to my family, mother Mrs. Janaki Devi, father Mr. Mahabir Mahato, wife Mrs. Kiran Kumari Mahato, brother Mr. Gobardhan Mahato and brother-in-law Mr. Abhishek Mahato, sister in law Mrs. Poonam Mahato, son Mr. Mohinder Mahato, daughter Miss. Diksha Mahato and Miss. Shagun Mahato for their patience, moral support, love, care, sacrifice and encouragement that made it possible for me to come so far.

Last but not the least, I pay my sincere thanks, love, and respect to all who have directly or indirectly helped during my doctoral research work.

Manohar Mahato

Place: Guwahati
Date: 10 October 2022

Manohar Mahato

FUNDING ACKNOWLEDGEMENT

The author acknowledges the Indian Institute of Technology Guwahati for appointing him as a Teaching Assistant and supporting the research studies conducted in India by the author under the supervision of Prof. Amarendra Kumar Das.

ABSTRACT

Design is considered as creative human activities which focus to improve living for all categories of people. Humans are weaving cloth through handloom and powerloom to fulfill their one of the basic needs in life. Handlooms have a long history beyond the available ancient history. Over the time, handloom improved through many inventions towards making powerloom available today primarily from industrial revolution. Whereas handlooms have many special features over powerloom like making tailor made fabrics for small quantity etc. These features are still fulfilling the special human needs through creative weaving by handloom which are not fulfilled by powerloom. Also, handloom sector is second largest employer after agriculture in India. It shows the number of people involved in the sector and its unique positioning in the textile sector. Exports of these handloom products have a huge opportunity in various countries of the world. Existing handlooms are very inefficient in production and tedious to weave, causes various work related musculoskeletal disorders to the weaver. It is found that very few research work have been carried out to improve directly to the weavers working conditions in compare to number of weaver affected in the handloom sector. In this research work, it has been studied to improve the handloom weaving through design intervention for commercial application useful in handloom cluster with higher productivity in reduced effort.

Existing handloom were studied through online and on field to know the state of art. Aim of initial study was to know working sequence of the loom by reviewing mechanism involved in different motion of the handloom and scientific study to improve efficiency of the handloom with ornamentation in weaving by low effort of weaver. There were people of research and academic institution who have initiated to improve the handloom. They majorly did this by imitating the mechanism from power loom. These semi-automatic handlooms with imitated mechanisms are very difficult to operate manually as they were made heavier to run by power. Handloom is made up of wood in general, whereas mechanism made by wood material cannot sustain for long due to wear & tear. Also, there is a concern to get suitable wood now a day. Maintenance is another problem with wooden non standardized handloom due to lack of expert carpenters. All these issues cumulatively make existing handlooms inefficient for commercial use and non-likable by surrounding weavers. This same issues have been concluded by the subcommittee made by government, to resolve and finalize the definition of handloom over getting benefit of reservation of products which can be made by only through handloom and not by power loom. Electricity is not available all the time in

majority of the weaving area, so power operated, pneumatically or hydraulically operated semi-automatic handlooms were not considered under this research. Production of handloom machine in mass was difficult in short time with wooden handloom. Modern manufacturing processes were not considered in existing design to produce the handloom in mass.

As a retrospective study, handloom census has been studied to get number of various types of handloom mostly used in handloom. A Fly shuttle frame handloom was taken for study as it is mostly used. Traditional handloom and existing semi-automatic handloom were reviewed through literature and by field study at Sualkuchi, Assam. ‘Semi-automatic handloom for women’ made by Das A under guidance of Prof V P Bapat from IIT Bombay and ‘Jute weaving semi-automatic handloom’ by Prof. Das A from IIT Guwahati were considered as base semi-automatic handloom to improve further in terms of efficiency and weavers comfort. All the mechanism involved in various motions was studied and compared with available alternative mechanism and selected the best suited mechanism for next process of design. As a next step, it has been designed and developed an alpha model for the semi-automatic handloom. All the mechanisms have been checked for their function and shape. After successful trial of alpha model, beta model designed by incorporating all the drawbacks found during various processes like material selection, manufacturing, inspection, maintenance, assembly, dis-assembly, packaging, transport etc. Picking motion by Burmese type picking mechanism has been synchronized with beat up motion with bottom pivot for sley oscillatory movement. Base structure has been made lighter with sheet metal design by shifting the pivot of sley at bottom instead of top in existing available semi-automatic handloom with Burmese type of picking mechanism, causes heavy structural frame of handloom. Gear mechanism for take up motion has been redesigned to compact shape and to avoid backlash problem in existing design. Paddle has been introduced for foot comfort in shedding motion. Adjustable seating system, treadle and beat up handle has been designed considering the repetitive movement of hand and leg. Spinning wheel, Creel, warping drum and jacquard also redesigned with sheet metal for proper synchronization with the newly designed semi-automatic handloom named as ‘De sign Loom’.

This research established that the De sign loom is more productive with enhanced productivity, better human factor contribution and aesthetically pleasing form, much affordable, easy to manufacture and easy to use. Laser cutting process of sheet metal and computerized bending are preferred to avoid costly tool room operation. It has also substantially improved the quality and productivity during manufacturing of the loom. Also, all the related accessories like jacquard, creel, warping drum were designed and developed in sheet metal. Also, it is modular type for using plain weaving as well as for ornamentation too with additional attachment. There is also provision to use Chaneki, an extra weft insertion device along with this loom with an additional frame.

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Chapter 1: Introduction to Handloom Weaving

India was self-sustainable in textile till the 1780s till machine-made yarns and clothes started coming from England. British did not intentionally empower the Indian textile industry to weaken the handloom sector for promoting and selling their imported clothes in the vast Indian market.

1.1 Importance of the handloom sector

Regional self-sufficiency is the ultimate goal of any sector planning, study, and research. The agrarian society's economy is surrounded by producing and maintaining crops and farmland. The people of agrarian society have to buy very few crops and spices to fulfill their remaining food needs. The community of agrarian society becomes self-sustainable if they incorporate handloom weaving into the culture to meet cloth as another basic need of human beings. They can sell the surplus crop and fabric from agriculture and weaving to fulfill their remaining need respectively that people demand. Design and fashionable trend through creativity plays a vital role in fulfilling the clothing needs of all generations where people' interest keeps changing over time. In practice, hand spinning and hand weaving are off-season activities after completing seasonal agriculture activities. Education and health are two more critical needs of human beings, mostly taken care of by the central and state government in India. The remaining luxurious need might be compromised or put additional effort in case of low earnings and emergencies in the family. The community's human mind, whose food, cloth, house, education, and health facility are readily available, performs better in any work and is primarily creative.

Handloom sector in India

In ancient India, there were activities in fine arts and crafts mentioned in the list of 64 Kala like suchikarma - the art of needlework and weaving, sutrakarma – the art of playing with thread, and turkakarma – the art of spinning by the spindle. India was firm and self-reliant in the handloom sector before the British rule in India, with various unique designed products in traditional design. Traditional textile designs of India are Phanek from Manipur, Muslin of Chanderi, Varanasi brocades, tie and die products of Rajasthan and Orissa, Patola sarees from Patan, Himroos of Hyderabad, Phulkari and Khes from Punjab, Daccai and Jamdani from West Bengal.

India was once known worldwide for their exclusively woven delicate handloom fabrics. The textile was one of the primary export items in trade from ancient India. However, the British occupation of India discouraged the Indian handloom industry in favor of their mechanized mill product; for them, India was just an overseas market. Later, post-independence, the Government of India did not focus much on the handloom sector until the formation of ‘The All India Handloom Board’ in 1952 to propose a scheme for developing this sector, causing null growth in that period.

Handloom weaving gained prominence as an outcome of the freedom struggle in India. Handloom acted as a device to fight the foreign occupation of India by boycotting foreign goods and wearing hand-woven khadi; thus, it was primarily associated with patriotism and simple living. However, khadi differs from other handloom materials as khadi fabrics are hand woven with hand-spun yarn only.

Indian freedom fighters and leaders stood for the handloom industry by wearing khadi and boycotting foreign materials. Although it saved the handloom weavers to some extent, it had an adverse unforeseen side effect. Handloom cloths in most parts of India have become associated with the image of patriotic citizens simply in an austere manner. This image is not precisely conducive to fashion and colorfulness and did hamper handloom textiles in this aspect. In the late eighties, the glory of the handloom cloth was back to normal. It was breaking away from its simplistic image to exclusively designed fashion items out of the ordinary person's reach.

The involvement of national leaders in khadi led to various developments in hand-spinning machines and handlooms. There is an improved loom, named Sewagram loom designed and developed in that period. Other looms such as the Chittaranjan loom, Banarsi loom, Madanpura loom, and Nepal looms were developed in the private sector.

Growth of power loom after independence took a significant market share of handloom, followed by globalization to shift competition from national to global. Still, the handloom sector is the second largest after agriculture based on employment in India.

In India, the government is still very eager to promote handlooms because of their high potential for providing mass employment and thus improving the economic condition of many of the poverty-stricken citizens. To achieve this through its economic policies, the government assists weavers financially and technically by setting up weaver's service centers, handloom institutes, and holding handloom trade expos. Handloom inputs, machines, and equipment are made available with a subsidy to achieve desired results in every possible sphere of its activities.

“India produces 85 percent of handloom products of the world. Other countries having handloom industries are Sri Lanka, Nepal, Bangladesh, Norway, West Indies, Indonesia, Pakistan, Iran.” [1]. “There are 3.522 million handloom workers in India. In India, nearly 3.144 million of handloom households are engaged in weaving and allied activities[1]. The total weaver household units declined from the first handloom census (1987-88) to the fourth handloom census (2019-20). Fifty-seven percent of the handloom households live below the poverty line (BPL). A total of 69 percent of the handloom households undertake commercial production. Nearly 31 percent of handloom worker households do not have looms [1]. Seventy-six percent of adult handloom workers are contract workers in states except for the North-East region [2]. 67.1% of the household of handloom workers earn less than ₹ 5000 per month, and 97.8% of the household of handloom workers earn less than ₹ 15000 per month [1]. The share of handloom income to total household income is 30.2 percent across all handloom households [2]. Only 0.12%, i.e., 3590 households of handloom workers across India, earn more than ₹ 50000 per month [1]. A detailed study on these 0.12% households can help other households of handloom workers by following them to improve their income.

In this research, the handloom machine is mentioned as handloom, and the outcome of handloom as fabrics are mentioned as handloom product.

1.2 Merit and demerit of the handloom weaving

Merit of Handloom sector

i) Heritage and the tradition of excellent craftsmanship

ii) Low level of capital investment

iii) Availability of high-skilled labor

iv) Informal school for skill generation and transfer of technology

v) Opportunity to generate mass/self-employment

vi) Opportunity to work from home, family members can work jointly

vii) The cost of employment generation is significantly less

viii) People can work in co-operative groups / Self-help group

ix) Many SPVs (Special purpose vehicles)/SHGs (Self-help groups) are exporting directly

x) Many high-end retailers like IKEA, Walmart, Amazon, H&M, Zara Home, and Primark are selling handloom products

Demerit of Handloom sector

i) The number of handloom workers (6.55 million to 4.3 million from second handloom census in 1995-96 to the third census in 2009-10 and further declined to 3.1 million in fourth handloom census in 2019-20) is declining sharply

ii) Shifting of skilled weavers to other sectors

iii) The younger generation is not adopting the weaving profession due to lower wages, harsh working conditions

iv) Severe constraints of credit availability

v) Concern for the availability of yarn for scalability

vi) Outdated know-how

vii) Imitation of high-demand designed handloom product through power loom

viii) A centralized production facility and handloom cluster development initiative may make it centralized for easy implementation of sector improvement policy

ix) Production is more or less constant year on year

Merit of Handloom

i) The flexibility of production in small quantities

ii) Openness to innovation

iii) The weaving of the intricate unique designed fabric, its versatility & wide variety of diverse design base

iv) Possibility to weave short pieces of fabrics

v) A quick switch over to a new design

vi) Possibility to make many designs and patterns as Zari work, Jamdani work where more setting time required, therefore, cannot be imitated in a power loom meant for speedy weaving

vii) The traditional mode of production with low technology, electricity not required

viii) Eco-friendly technology/process

ix) Possibility to weave with extremely fine material, i.e., yarn of counts above 20s

x) Possibility of interweaving with gold and silver thread

xi) Possibility to weave multi-colored designed fabrics

xii) Possibility to weave embellishment in the border and headings

xiii) Possibility to weave rough cloth of very low counts such as durries, niwars, where the tensile strength of the yarn is too low for the mills

xiv) Customization is possible even for small handloom

Demerit of Handloom

i) The low productivity in comparison to the power loom and mill sector

ii) The limited scope of technological up-gradation and improvement in a weaving activity

iii) Obsolete technology leading to low production causes less earning to weaver

iv) Low interest in design or technological intervention by intellectuals due to decentralized scattered small-size cottage industry

v) The heavy shuttle is used for carrying very light weft yarn[3]

vi) A shuttle may fly due to unguided movement[3]

vii) Frequent pirn changing in the shuttle abrupt continuous weaving

Merit of Handloom product

i) Heritage and the tradition of excellent craftsmanship

ii) Possibility of tailor-made weave ornamentation of each fabric

iii) Soft to touch and luxurious weaving

iv) Oil stains free fabric

v) Handloom products suitable for all climate

vi) More thread per inch of the woven fabric

vii) The vast overseas market for customized product

Demerit of Handloom product

i) Wavy and uneven edge and uneven finishing

ii) Reed mark stands out as spacing between picks

iii) Pin mark of the wooden temple on the edge of the fabric at regular intervals

iv) Start mark may be visible due to frequent pirn change and restart weaving again

v) Low cost of production and high productivity with mass manufacturing has facilitated products from power loom to dislodge simple handloom products from the preference of the ordinary person

vi) Lack of uniformity in texture causes difficulty in remaking similar products in case of high demand or repeatable orders

vii) The exact dimension is difficult to achieve

Traditional handloom is generally made up of a wooden frame. It hinders satisfying, sustainable goals. Also, it is challenging to get the required quality wood with consistency, and even if the wood is available, skilled carpenters are unavailable across local areas. Traditional handloom is challenging to manufacture with consistency, repeatability and reproducibility. It is difficult to interchange the parts of the handloom due to lack of standardization during manufacturing and hence maintenance is an issue. Wood as a material restricts many of the characteristics during manufacturing, such as parallelism between the front beam and warp beam, front post, and rear post, and sley with warp beam. Every part is like making new customized parts in a wooden handloom during replacement.

Process of handloom weaving

Before actual weaving, a few essential pre-weaving processes are shown in the flow diagram in Figure1.1.

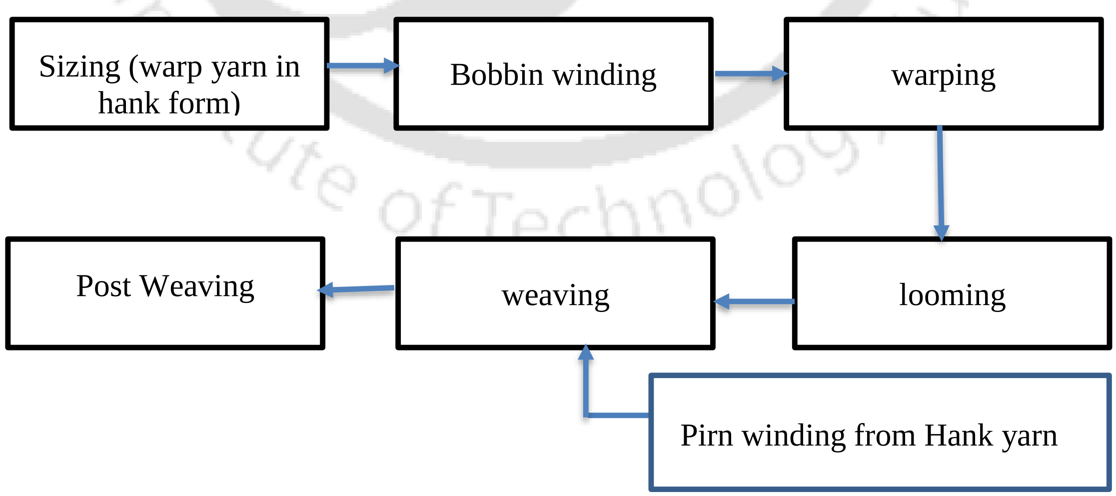


Figure 1.1: Process flow chart showing handloom weaving process

Brief definitions of various terms related to pre-weaving and weaving processes are as under:

Sizing: it is the application of a coat of adhesive material onto the warp to achieve functionally desirable results, like imparting additional strength to the warp yarn to withstand stress and strain during the weaving process. Sizing is essential for single/hand spun yarn.

Winding: It is the conversion of yarn to a functionally suitable package for the subsequent processes, such as bobbin winding for warp yarn before the warping process and pirn winding for weft yarn before weaving.

Warping: It is the process for the conversion of individual warp yarn into a sheet of yarn called a warp sheet suitable for mounting on a loom prior to weaving. Yarn from the industry is available in cones and bobbins. Yarns from cone and bobbin are further converted into hank form through the machine and dyed. Yarns are dyed in hank form in the handloom sector. These hank yarns have been used to make warp sheets in limited length due to the requirement of open space during the warping process. Yarn entanglement is challenging and causes more warping time to keep each yarn in parallel. More space requirement is another problem in this process. Varied tension throughout the width of the warp sheet due to the form of the beam or additional stick attached for knotting or parallelism with the front beam and reed are micro-level concerns with the traditional handloom. Warping and weaving are not synchronized to make quality fabric in the traditional way of working.

Looming: Also called gait up, it is the process of mounting the warp sheet onto the loom and preparing it for weaving after passing it through healds and reeds etc., and tieing up the healds or harnesses for shed formation in desired interlacement pattern.

Weaving: Weaving is the process of forming fabric by interlacing a minimum of two sets of yarn, namely warp and weft, in a predetermined pattern. The woven cloth comprises warp threads and weft threads interlaced with definite interlacement. As mentioned earlier, weaving is the process of the formation of fabric in the loom. Primary motions are shown in Figure1.2. The weaving cycle consists of the following motions:

Shedding: Creating the shed by separating the warp sheet into two layers in a predetermined pattern for interlacement with the weft yarn. Shed formation is of center close type in plain weave and bottom close type in case of ornamentation through dobby/jacquard attachment. Shedding is done through bamboo or wooden treadle without enough foot support for a long duration working in traditional handloom. The size of shed formation constantly changes due to fixed warp sheet and addition of weft, reduces swing displacement of sley. Also, it can vary with force exerted on the treadle because of the tiredness of the weavers.

Picking: Passing the weft yarn by shuttle passing through the shed is called picking. The shuttle contains the weft yarn winded on the pirn. Picking may not occur appropriately if the reed is not parallel with the warp sheet. The path of shuttle movement varies continuously due to the changing shape of the shed. Manual picking is tedious for working long. Changing force for picking may break the weft, interrupting regular weaving; also, weft yarn may not be straight positioned due to varied hand force before beat-up occurs. Work-related musculoskeletal disorders of weavers can be seen in Table 1.1.

Table 1.1: Number of weavers suffering from occupational health problems due to weaving operations: N=70.[4]

SL No	Health hazard	Frequency (percentage)
1	Headache	17 (24.29%)
2	Spondylitis	22 (31.42%)
3	Shoulder pain	30 (42.86%)
4	Backache	35 (50%)
5	Pain in palm + Stiffness of hand joints	32 (45.71%)
6	Obesity	5 (7.14%)
7	Knee pain + Pain in calf musceles	30 (42.86%)
8	Breathing problem and chest pain	25 (35.71%)
9	Any hearing problem	10 (14.29%)

Beating: It is the process of beating the last picked weft using a beater. Irregular beating by two weavers in a single handloom product creates variable picks per minute in the fabric. Also, the single weaver will tire, causing variable beating across their working time. It results in variable pick spacing over the length of the woven fabric. Also, continuous hand movement with sley without handle put wrist joint in awkward posture during beat-up motion.

The above three processes are repeated cyclically to create the whole fabric.

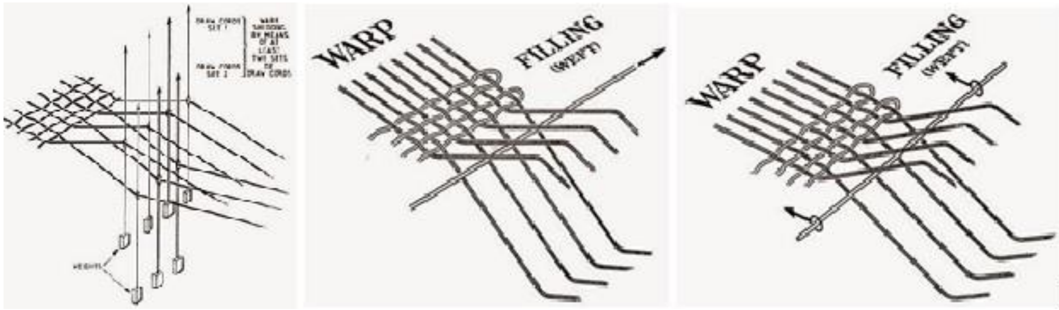


Figure 1.2: Action of warp and weft in Shedding, Picking, and Beat up motion[5]

Secondary motions are essential for the continuous weaving process, i.e., take up and let off.

Take up: Once the fabric is formed, it needs to be withdrawn for continuous fabric formation, and withdrawing the freshly formed fabric is called take-up. It needs to wind the fabric manually in a traditional handloom, which causes a regular interruption in weaving. It occurs 5-10 times in an hour, considering yarn count. Also, there is currently no provision to control the picks per inch with the fixed setup.

Let off: When the woven fabric is withdrawn from the working zone of the loom, a fresh warp needs to be released to continue weaving, and this process is called let off. It needs to wind the warp manually in a traditional handloom, which causes a regular interruption in weaving. It occurs 5-10 times an hour. Also, it impacts maintaining tension amongst warp-sheet. The parallel between all the essential parts like cloth beam, warp beam, and reed of the sley is crucial for the smooth running of weaving.

In addition to these two types of secondary motions, the third category of motion helps to produce quality fabric and increase loom productivity. This category of motion is called Tertiary or Auxiliary motion of weaving and commonly used in power looms. Different motions of this category are as under:

Temple motion: This is to maintain a constant width throughout the length and produce fabric with unbroken selvedge, i.e., the edge of the fabric. In traditional handloom, it is attached with fabric, so as weaving progress, it moves far from the weaving area. It regularly needs to change the temple position and creates many holes in the fabric. Fabric shrinkage may occur in case of the late change of temple position in a traditional handloom.

Warp protection mechanism: It prevents damage to the warp in case there is a malfunction in the shuttle propulsion and gets trapped inside the shed. Warp breakage can occur due to fixed warp sheet, cloth beam, warp beam, and backrest.

Warp stop: It stops the loom in case of warp thread is broken.

Weft stop motion: The loom is stopped in absence or breakage of weft during shuttle movement

Shuttle check: It prevents the bouncing of the shuttle when it enters the shuttle box.

Oscillating backrest: It maintains uniform tension in the warp sheet throughout the weaving process. The fixed backrest will not change during alternately created shedding and maintaining tension all the time.

Almost half of the handlooms are without dobby or jacquard attachment. These handlooms do not even have the provision to accommodate later if interested in adding it as an attachment for ornamentation. Non-availability of this attachment restricts them from weaving ornamented fabric and forcefully competing with power loom products. Plain weave is not suitable for handloom, considering the efficiency and productivity.

A loom is a weaving machine. In a loom, erratic movements to healds, shuttle, sley, and some other parts are required, and all the parts must be accurately adjusted to function in a regular sequence during weaving. There are manual motions corresponding with automated motions operated manually by the weaver and need proper synchronization in case of a semi-automatic handloom. In a traditional wooden loom, shedding is operated using legs, picking and beat up, carried out with the hand, and let off and take up is intermittent for which the weaver has to stop weaving and lose production at that time.

Loom classification

Loom can be classified based on the source of power to operate.

- Handloom
- Power loom

Loom can also be classified as follows depending on whether they use a shuttle or not and the method used to insert the weft yarn.

- Looms with shuttles
- Looms without shuttles
    - i) Gripper loom
    - ii) Rapier loom
    - iii) Water jet loom
    - iv) Air-jet loom

Looms can also be classified based on the technological improvements over time as below

- Hand Loom -All operations are performed manually.
- Shuttle Looms (first-generation handloom)
- Power Loom (non-automatic)- The shuttle's pirn is frequently changed by hand.
- Automatic Weaving Machines - A power-driven loom on which the shuttles or pirns are changed automatically.

A loom is termed a 'handloom' when it is actuated by human power without using electricity for weaving fabric. Handlooms (Reservation of Articles for Production) Act, 1985 defined a handloom as "Any loom other than power loom."

These definitions of handloom allow a reservation to handloom sectors by restricting the copying of handloom products by the power loom sector. Also, it will help to implement government schemes related to the handloom sector. Now a day's government of India is withdrawing the restriction through the reservation; therefore, some immediate and lucrative action is required for the handloom sector.

Handloom is used synonymously for handloom as machine and product come out from handloom. Handloom means handloom product on a few occasions like 'Handloom and Handicraft'; here, handloom represents handloom product. Similarly, with the India handloom brand with its logo, handloom means handloom product. Also, the handloom sector consists of pre-weaving, weaving, and post-weaving activity, not only weaving by loom. In this research, Handloom represents only handloom as a machine, unless otherwise specified like handloom product and handloom sector.

Handloom can be classified as below:

- Primitive loom (Warp-weighted loom and Horizontal ground loom)
- Back-strap loom
- Pit loom
    (1) Throw shuttle loom
    (2) Fly Shuttle loom
- Frame loom:
    (1) Throw shuttle
    (2) Fly shuttle
- Foot-treadle loom or Floor loom

- Semi-automatic handloom like Chittranjan loom and Hattersley loom

Primitive or throw shuttle loom

The oldest known depiction of a loom is found on a pottery disk dated 4,400 B.C. in a tomb at El Badari, Egypt.

Unlike the present-day Tapestry loom, a loom is traced back to Egypt during the 18th Dynasty (1567 - 1320 B.C.)

During the period 1766 B.C. to 1122 B.C., the Chinese had developed a more complex handloom for weaving silk in intricate patterns that were impossible to produce on a loom that could produce only two sheds.

A horizontal loom with a treadle-operated harness appeared in Europe in the 13th century and continued.

Looms changed very little until the 18th century. After the invention of the fly shuttle in the 19th century, different inventions increasingly mechanized and automated weaving. During the 19th century, handloom weaving reached the stage of extinct art in the western industrialized world. However, the later part of the 20th century saw a revival of interest in handicrafts and handloom weaving.

Fly shuttle handloom

The fly-shuttle looms are divided into two classes: Fly-shuttle pit-loom and Fly-shuttle frame-loom or four-poster fly-shuttle loom. Fly-shuttle removed the various limitation of throw shuttle handloom but introduced a strenuous picking mechanism where the weaver has to propel the shuttle continuously for weaving, and productivity depended on how fast one can weave by propelling the shuttle repeatedly. Fly shuttle handloom reduced the number of workers required for weaving. In 1940, approximately one-third of handlooms were fly shuttle handlooms. Weavers from Chennai, Mysore, Travancore, Cochin, and Bengal had shown early interest in adopting this new technology.

Semi-automatic handloom

A semi-automatic handloom stands between an ordinary handloom and a power loom, in which the weaver manually operates some of its motions. In contrast, others are mechanically operated without using electrical power. Semi-automatic looms are of several kinds, but the following are commonly used in the industry: Chittaranjan loom, Salvation Army loom, and Hattersley loom.

Current data on handloom

“There are 2.824 million handlooms in India, spread across the household and non-household units. 42.2 percent of handlooms are pit looms, out of which 28.4 percent of handlooms have dobby/jacquard attachment, and 13.8 percent are without this attachment. 31.5 percent of handlooms are frame looms, out of which 10.3 percent have dobby/jacquard attachment, while the majority, 21.2 percent, are without this attachment. Fifteen percent of handlooms are loin looms. The remaining 11.3 percent of handlooms are other looms like Inchakaranji looms, Chittaranjan looms, Malabar looms, Manipuri looms, Rajasthani looms, Pedal looms, and Kashmiri looms. [1] Loin looms are one type of primitive loom in which all weaving motion is operated by hand. Pedal looms are semi-automatic looms that only shedding motion is done manually and restrict ornamentation. In an age in which shuttle-less looms can run at 1500 ppm (picks per minute), it is worth noting that shuttle looms running at 110–250 ppm are widely used, particularly in the developing world [6]. Against this speed, the handloom has a maximum average of 30 ppm only. Fly-shuttle looms use a mechanism and does not move the shuttle manually; therefore, an average weaver can run a medium-width fly shuttle loom at 80 to 100 picks per minute [7]. Also, it is found that only 33% of frame looms are using dobby/jacquard for ornamentation, which is a significantly more minor number. Other frame looms are used for plain fabric weaving, which will not increase the earnings of weavers.

Overall weaving capability of India as of 2008 in terms of available looms can be seen in Table 1.2 [8] in comparison to other countries

Table1.2: Weaving capability of India with other countries

Items \ Country	**India**	**China**	**Pakistan**	**Indonesia**	**World Total**
Shuttle less looms (Nos.)	58489	527700	28383	51760	1200660
Shuttle looms (including filament weaving looms & wool weaving looms)	2219548	911926	575000	226000	4616779
Total Loom	**2278037**	**1439626**	**603383**	**277760**	**5817439**
Ranking	**1**	**2**	**3**	**4**	
Contribution to the world (%)	**39.16**	**24.75**	**10.37**	**4.77**	**100**
Ratio of shuttle less looms to total loomage (excluding handloom) %	2.57	36.66	4.70	18.63	20.64
Items \ Country	**India**	**Bangladesh**	**Pakistan**	**Nepal**	**World Total**
Handloom (Nos.)	3890000	498000	80000	70000	4588000
Ranking	**1**	**2**	**3**	**4**	**---**
Contribution to the world (%)	**84.79**	**10.85**	**1.74**	**1.53**	**100**

Source: Compendium of International Textile Statistics – 2009

1.3 Scopes of design intervention

There are 5457 non-household units with 122302 looms and 0.265 million handloom workers. Non-household units are commercial units solely for marketing/sales/wholesale/retail with production-related activities (weaving and allied work). Three thousand two hundred eighty-one of the non-household units (60.1%) have reported idle looms due to lack of market demand (50%), non-availability of weavers (27%), and lack of capital/funds (23%). The required support details are shown in Table 1.3 by the weaver household based on the fourth handloom census 2019-20.

There are many areas where intervention is required to improve the weaver households. Technology up-gradation is an area chosen based on the expertise and facility available.

The maximum household from Assam has requested various support, which shows their interest in preserving this sector.

Table 1.3: Nature of support needed by weaver households (2545312)[1]

Nature of support	Handloom household (%)
Calendaring (Finishing)	51.4%
Dyeing (coloring – dyeing, natural)	51.9%
Management training (marketing, computer literacy, visual merchandising, packaging, accounting, market information, export procedures)	52.9%
Technology up-gradation (dobby, jacquard, warping machine, take-up motion, steel reed)	54.8%
Marketing support (e-commerce, exhibitions (international and domestic))	55%
Technical training (jacquard, jala, weaving, dyeing)	55.6%
Design support (Design and designer)	56.4%
Credit support (waiver, loan)	58.4%
Raw material support (in hank form – cotton, silk, wool)	59.5%

1.4 Research questions (RQ)

A 1. Are pre-weaving processes like warping essential to enhance the productivity of a handloom?

B 1. How can the working efficiency of a handloom be enhanced?

B 2. What factors contribute to the enhanced quality of the woven fabric?

B 3. How can value addition be achieved in a loom?

B 4. What type of ergonomic intervention is essential to enhance productivity without higher physical exhaustion?

C 1. What are the shortcomings of wooden frame handlooms?

C 2. Can the loom-making process be changed to achieve a better product and process?

1.5 Research gap

The handloom sector is suffering from low productivity, causes low income, and is full of drudgery due to age-old technology and equipment. Thus, the present youth does not wish to continue this activity. Picking motion, where wept yarn in a shuttle is inserted between the warp yarn, is tedious and monotonous.[9]"

“Handloom sector is unorganized, lacks raw material, marketing facilities, training, and financial assistance, and suffers from the greedy middleman. There was a policy on de- reservation from handloom sector, which will increase competition from power loom/mill [10]”. There is a significant threat of de-reservation of the Handloom act 1985 for the related workforce. Developed countries are putting pressure on the Government of India for not giving exporters subsidies and other monetary rewards because it is against WTO protocol and free trade [11]. After globalization, traders faced more problems selling their goods and services due to heavy competition and complex import and export processes [12]. A fishbone diagram is shown in Figure1.3 to know all the influential factors contributing to the unhealthy living environment of weavers [13]. However, adopting modern techniques and economic liberalization has created severe problems in the handloom sector. Competition from power looms and mill sector, availability of cheaper imported fabrics, changing consumer preferences, and alternate employment opportunities have threatened the vibrancy of the handloom sector. “Rural manufacturing employment is declining day by day. There are two main factors for the decline of rural manufacturing employment,

i) Sluggish global demand for major export items like textile, and

ii) Employment generation by Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS) [14]”.

Moving from framing policies that protect the sector to thinking that presupposes handloom can survive only by competing in the mainstream market, we can see the policies for handloom have come full circle. Today, the danger is not too specific to handloom product identities but to handloom itself[15].

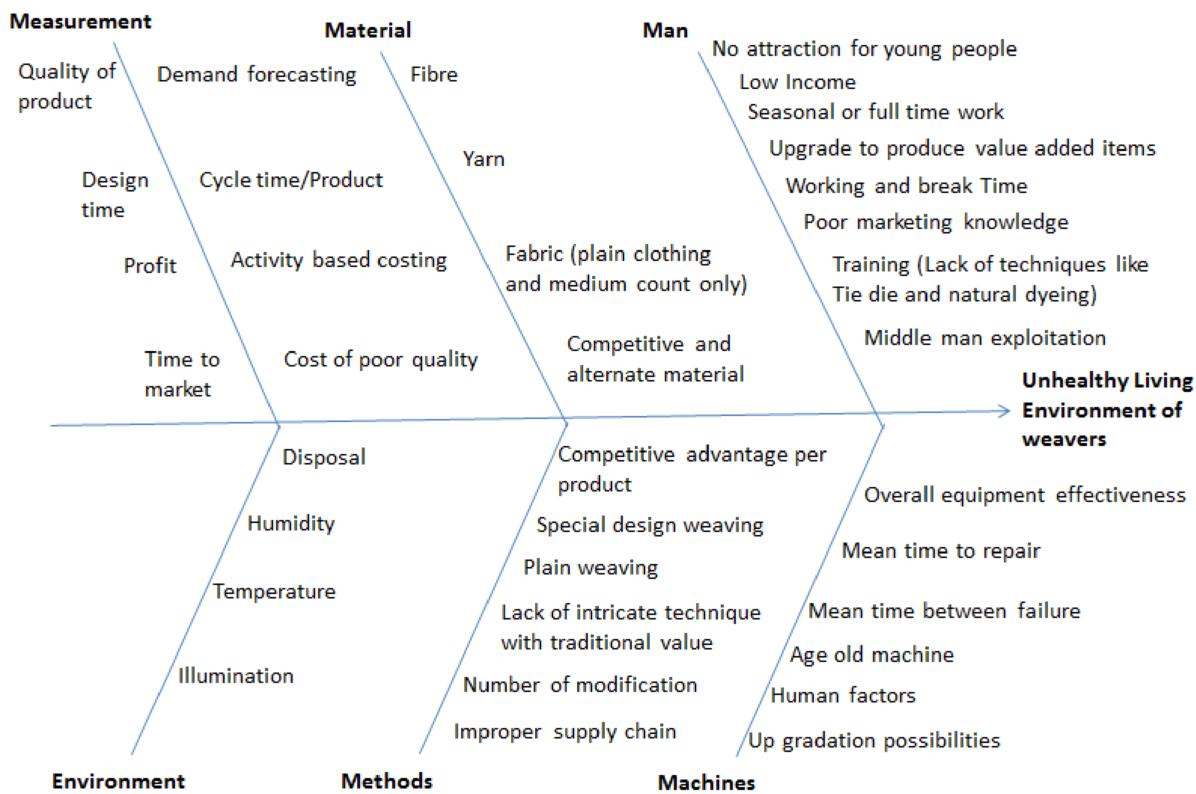


Figure1.3: Factors contributing to the unhealthy living environment of weavers

1.6 Aim and Objective

Aim: This design research aims to identify an appropriate semi-automatic handloom, improve design and development to make weaving comfortable, facilitate value addition to its product, and design alternative manufacturing for mass manufacturing of handlooms in alternative materials.

Objectives:

1) Study handloom to identify appropriate weaving motions from Primary, Secondary, and Tertiary to decide on Combinations for arriving at one for further development to enhance ease of weaving, productivity, and value addition to its products.
2) Study existing Semi-automatic handloom (if any) to identify appropriate one for further development:

   i. to enhance ease of weaving, productivity, and value addition to its products.

   ii. for manufacturing, considering materials and process.

3) Design and develop a semi-automatic handloom based on identified semi-automatic handloom (in objective 2) using alternative materials and design to enhance the ease of manufacturing and assembly process, ease of packing and transportation, and assembly of the loom, at the weaver's end.
4) Prototyping of the Alpha type, testing the loom for functional validity followed by Beta type and testing the loom by weaving cloths to validate ease of weaving, productivity, and facility for value additions.
5) Design and development of accessories to compliment the semi-automatic handloom's productivity

1.7 Research Methodology

Research methodology steps are studying existing looms and their features to identify problems, designing an appropriate semi-automatic handloom, prototyping, and testing, and commercialization.

The experimental and descriptive approach under the qualitative design methodology was followed to identify the problem in the handloom. Research by design and creative design methods are used, such as brainstorming after thorough literature and product review.

The design methodology adopted is two-pronged

1. Holistic Approach
2. Piecemeal Approach

Holistic Approach

The handloom as a whole is considered in the holistic approach, and possible structure as a whole is explored considering functional requirements. In this case, the constraint was using available structural members like L-member, square rectangular, and round cross-sectional tubular structural members. Another constraint was to explore the structure keeping in mind easy disassembling, packing, transportation and reassembly. Based on these, several concepts were developed.

Piecemeal Approach

In the Piecemeal approach, all different sub-systems of the loom are explored separately by studying the existing mechanisms from looms irrespective of handloom or power loom. Then different systems of that sub-system are compared, and only those compatible with the semi-automatic handloom are adopted with the required design input.

This design research was initiated based on the above understandings. Instead of initiating a new design for an appropriate semi-automatic handloom, work was started considering an existing semi-automatic handloom known as the Shanti loom (1990), which was fabricated in mild steel with a wooden sley. Shedding was independent of Picking and Beat-up motions to facilitate weaving structural design cloth and extra ornamentation. Picking was a traditional fly-shuttle type, and beat-up was synchronized with the take-up motion and, in turn, with the let-off motion. Temple motion worked in conjunction with the automatic take-up of cloth.

This research is based on the actual study of handlooms and available product information on semi-automatic handlooms in print and the web. The handloom structure was to be modified for essential human factors, and picking and beat-up may be required to be integrated so that the weaver no longer propelled the fly shuttle through the hand. Picking can be achieved by pushing the sley rearward like the Burmese-type cam-actuated picking mechanism that automatically propels the shuttle from one end to the other. The pushing of the sley will automatically reverse and complete the beat-up action by conserving the inertia of the sley if crank mechanism is integrated. This type of new picking mechanism will reduce the weaver's drudgery and will not affect the loom's ornamentation capability in woven fabrics. Also, it was decided from the beginning of the research that minimum mechanical devices will be used so that the weavers can operate and maintain these semi-automatic looms.

Various modern manufacturing techniques can be considered to facilitate mass production of the designed loom under DFM and DFA. Outcomes of the design research are to be acceptable by the stakeholders.

The complete methodology for the research is illustrated below in Figure 1.4.

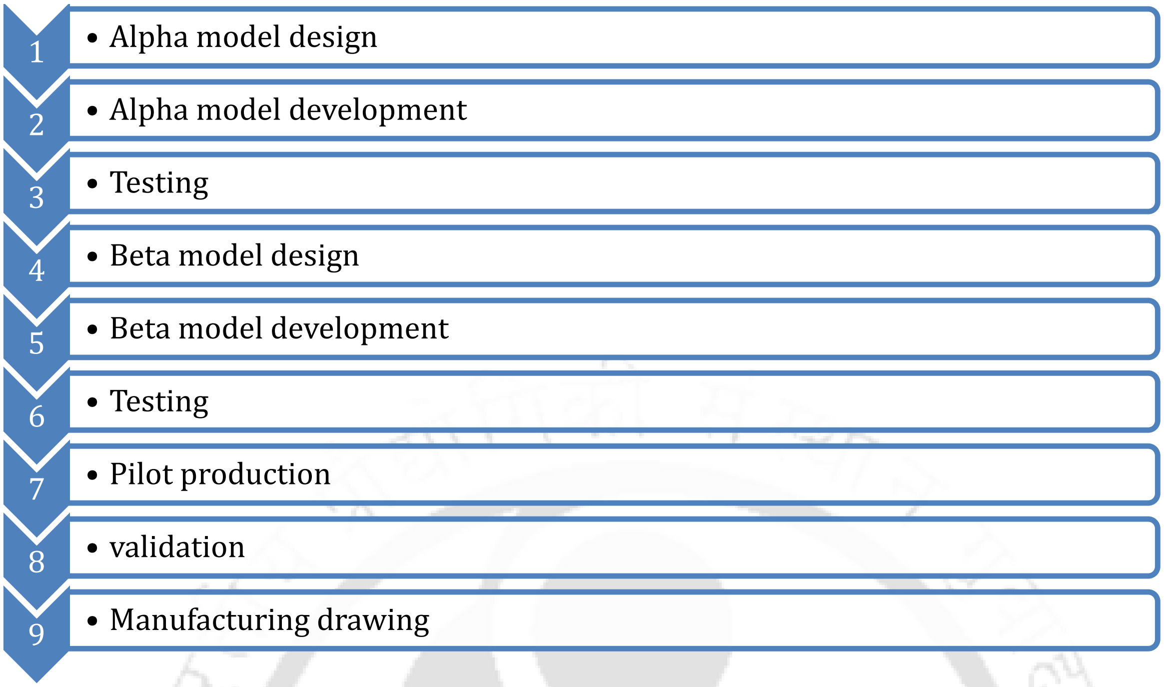


Figure 1.4: Research methodology

This research is targeted at handloom designers, machine manufacturers, weavers, researchers, and innovators in this sector.

1.8 Expected outcome from the research

To make handloom sector attractive, the weaving machinery has to be developed or designed to remove drudgery and increase its productivity to make it economically viable avocation. Thus, technological advancement and ergonomic intervention in handloom are most important factors, which need attention from the scientific community. It is necessary to improve productivity and comfort of weavers to avail the opportunity to expand the market.

New semi-automatic handlooms should have capability for higher production, value addition to its product through extra warp/weft ornamentation, cost-effective and easy to transport and assembly, reliable and easy to maintain. Also it should be weaver friendly and have a superior synchronization between weaver, loom and their environment.

1.9 Validation

The validation of the design of the semi-automatic loom in terms of various objectives mentioned earlier will be carried out through actual weaving including meterage woven in unit time by comparing with traditional handlooms. Weavers from Sualkuchi – Assam's silk weaving centre, Guwahati, Assam Apex Weavers and Artisans Cooperative Federation Ltd (ARTFED), Handloom development and research center, Department of Handloom and Textiles, Government of India etc. are to be engaged for trial.

1.10 Conclusion

Every motion has to be analyzed through the various alternative available with their advantage and disadvantage in choosing the right fit for the new semi-automatic handloom. Existing handloom and semi-automatic loom are to be studied with the mechanism of each motion. Also, the semi-automatic handloom to be designed is to be checked for its ornamentation capability smoothly as and when required. Productivity is to be improve by at least 50%, and the durability and mass manufacturability to be improved significantly through ease of processing using advanced manufacturing processes such as laser cutting and CNC bending. An existing loom is to be considered as a reference loom that is commercially successful model and physically available nearby.

Regarding ease of packing and transportation, the most significant part and sub-assembly size are to be based on the local cargo vehicle for easy and cost effective distribution. The loom should be easy to assemble and disassemble. Accessories like spinning wheel, Creel and warping drum, seating system, and jacquard are to be designed to synchronize input, process, and output properly.

1.11 Structure of the Thesis

Chapter 1 introduces weaving, the history of weaving, and handloom with current data on weaver, handloom, yarn, and products woven. It also touches upon various merits and demerits of handloom, looms classification, and research design. The aims and objectives of the doctoral research are also covered here based on various research questions raised.

Chapter 2 covers details of the literature review process with subheadings like handloom, semi-automatic handlooms, weaver health and economical condition, semi-automatic to automatic convertible loom, automatic loom converted from handloom, and literature on accessories like winding wheel, creel and warping drum, seating system, jacquard etc.

Chapter 3 explains the research methodology followed for the design and development of semi-automatic handloom and allied accessories.

Chapter 4 explains the design and manufacturing process of semi-automatic handloom where an alpha model was prototyped with readily available resources from the institute workshop followed by a beta model manufactured through commercial metal processing industry.

Chapter 5 explains the design and manufacturing process of accessories related to semi-automatic handloom, like winding wheel, creel and warping drum, seating system (except jacquard), etc. through an alpha model manufactured with readily available resources from the institute workshop followed by a beta model manufactured through commercial metal processing industry

Chapter 6 includes findings during the design and manufacturing of semi-automatic handloom and discussions on all success and failure steps of each design irrespective of small or big part or assembly

Chapter 7 is the concluding chapter of the research work and justification of the findings and results of the research, considering the research questions and aims and objectives framed thereafter. Contributions of the research, limitations of the research and possible future research work is also mentioned in this chapter to further improve the handloom and thereby the handloom sector by improving the livelihood of a weaver and allied workers associated with it.

Chapter 2: Literature Review and product survey

In this chapter, the contribution of the handloom sector to the GDP (Gross domestic product) and society of India has been explored. A real contribution to GDP is not essential for this sector as most sales occur in the local market, but the social importance of this sector is significant. Broadly this sector is explored through a top-down approach. The existing processes of textile manufacture were explored, from fibre to yarn to fabric. Thereafter, handloom products, input materials (yarn, dye), handloom workers, pre-weaving processes, and weaving processes are studied for a broader understanding of the sector. Handloom workers like weavers and allied workers have been studied in detail to know the status and capability of the existing workforce. The current status of the tools for pre-weaving and loom for weaving, limited to handloom, have been explored with their productivity, limitation, and scope for design intervention. Sales of handloom products through various channels, including export, to identify the sales trend and value-added products. Finally, the impact of various policies implemented through government agencies to improve the value chain at all stages of the production-consumption cycle were studied.

Contribution of Textile Industry to Indian Economy

2.1. Indian economy and manufacturing sector

Primarily Indian economy has been divided into three major sectors: agriculture, industry, and service. The industry sector is again classified into four sub-sectors: mining & quarrying, manufacturing, 'electricity, gas, water supply & other utility services,' and construction. The manufacturing sector can also be classified into five categories: Food Products, Beverages and Tobacco', 'Textiles, Apparel and Leather Products, Metal Products, Machinery and equipment, and other manufactured goods [16].

Table 2.1: Sectorial employment share after liberalization

	India		China		USA	
Sectors	1991	2016	1991	2016	1991	2016
Agriculture	62.70	45.10	54.90	27.80	2.90	1.50
Industry	15.40	24.30	19.40	23.90	25.70	17.20
Services	21.80	30.60	25.70	48.30	71.40	81.30

Source: World Bank

It can be seen in the sectorial changes in employment after globalization in 1991 through Table 2.1 and sectoral GDP share from 2011 to 2021 in Table 2.2. According to Lewis's economic growth framework, an economy gradually transforms from a low productive sector to a relatively high productive sector. The manufacturing sector within the industry sector can absorb the excess amount of labor from the agriculture sector and move the same to services, rendering it the driving force in the development force of an economy [16]. Also, the same movement by the workforce has been seen through Three-Sector (or Fisher-Clark-Kuznets) Hypothesis [17]

Table 2.2: Sectorial GDP share after liberalization[18]

	India		China		USA	
Sectors	1991	2020	1991	2020	1997	2020
Agriculture	27.3	18.5	24	7.7	1.3	1.1
Industry	26.4	23.9	41.5	37.8	23.1	19.4
Services	37.8	48.9	34.5	54.5	71.8	79.5

Source: World Bank

There are two trends observed in the industry sector's growth after liberalization; first, the industry sector had been growing faster than the whole economy, and second, registered manufacturing firms are performing better compared to the unregistered manufacturing sector [16]. Therefore, the problems of unregistered manufacturing firms are emphasized to grow equally.

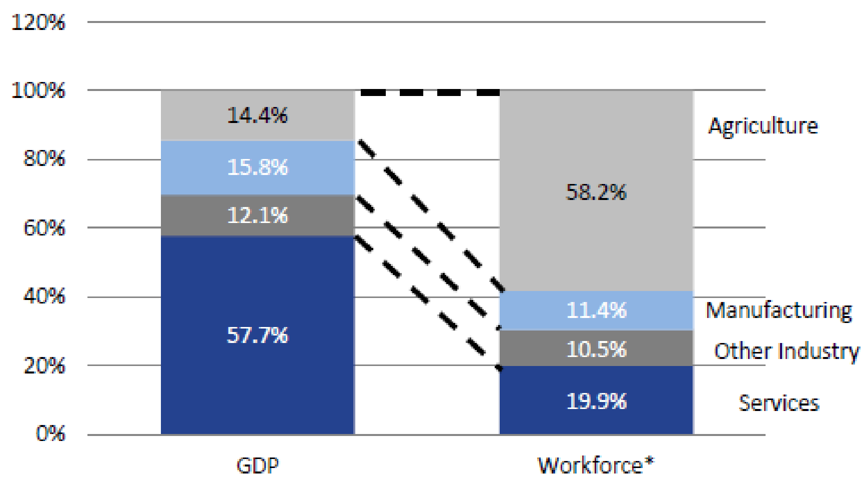


Figure 2.1: Employment distribution across the sector in India (FY11)

Source: RBI (GDP data); Economic Survey (Workforce data)

The 12th five-year plan (2012-17) identified the requirement of another 250 million jobs for additional job seekers joining the workforce in the next 15 years [16]. It was planned to create additional 100 million jobs in the manufacturing sector. "It has been emphasized in the key manufacturing sector for employment generation like textiles, leather, food processing, gems, jewelry, etc. "Present status of the manufacturing sector in terms of workforce and GDP has been shown in Figure 2.1 concerning other sectors in the Indian economy. Also, the worldwide surplus population in the working-age group can be seen in Figure 2.2 based on the current plan to create employment, indicating special attention to solving the problem [19]".

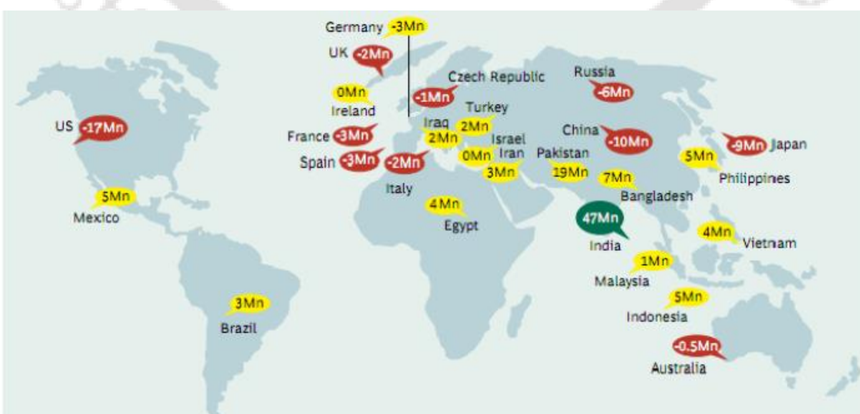


Figure 2.2: Potential surplus population in working age group by 2020

Source: US Census Bureau, CII-BCG Report, Aranca Research

"The National Manufacturing Policy introduced in 2011 to increase the share of manufacturing in the GDP from 15-16% to 25% by 2025 and employment to 100 million additional job seekers. There are various sub-sectors under the manufacturing sector, which has shown in Table 2.3 concerning their share of gross domestic product (GDP) of the manufacturing sector [16]".

Table 2.3: Share on manufacturing GDP of various sectors under manufacturing sector

Description	**1950-51**	**1955-56**	**1965-66**	**1979-80**	**1989-90**	**2000-01**	**2009-10**
Food Products	25.3	23.0	15.2	9.1	10.8	9.5	8.2
Beverages and Tobacco Products	1.3	1.2	1.5	2.3	2.3	2.7	2.8
Textile Products	21.6	23.2	18.7	18.0	**15.2**	**16.1**	**14.0**
Leather & Fur Products	1.4	1.1	0.9	2.1	1.7	1.9	1.3
Wood & Wood Products, Furniture, Fixtures etc.	47.0	42.6	42.3	26.3	11.3	6.0	3.9
Paper and Printing etc.	1.6	1.7	2.3	3.3	4.0	2.8	2.9
Rubber, Petroleum Products etc.	1.7	2.6	2.6	5.7	10.1	10.5	11.3
Chemical and Chemical Products	3.6	3.5	4.6	6.5	8.5	12.0	13.0
Non-Metallic Products	1.5	1.6	2.5	4.3	5.7	6.6	7.3
Basic Metals	13.2	11.5	19.1	11.4	11.0	13.1	10.3
Metal Products and Machinery	1.9	2.7	5.8	11.3	11.7	10.3	11.8
Electrical Machinery	0.2	0.2	0.7	1.4	2.8	3.3	6.4
Other Manufacturing	7.9	7.9	7.3	3.3	5.5	5.2	5.3
Transport Equipment	3.6	4.8	5.4	5.5	5.8	6.6	8.2
GDP in manufacturing	100	100	100	100	100	100	100

Source: National Accounts Statistics

Every sub-sector has made a strategic plan to get the required outcome in terms of increasing GDP and employment. In Table 2.3, it can be observed that textile products have highest share on GDP over other sub-sectors within the manufacturing sector after liberalization. Share of manufacturing GDP for traditional industries like food products, textiles, and wood have declined while modern industries like machinery, transport equipment, chemicals, and metal products have improved their share. The ministry had made a Strategic Plan (2012-2017) for the textile Government of India to achieve the planned outcome.

The textile sector is suitable for India based on the sufficient availability of workforce, machines, and raw materials, making it a self-reliant industry. Employment potential, labor efficiency, and capital efficiency of the textile sector are shown in Figure 2.3, Figure 2.4, and Figure 2.5, respectively [19].

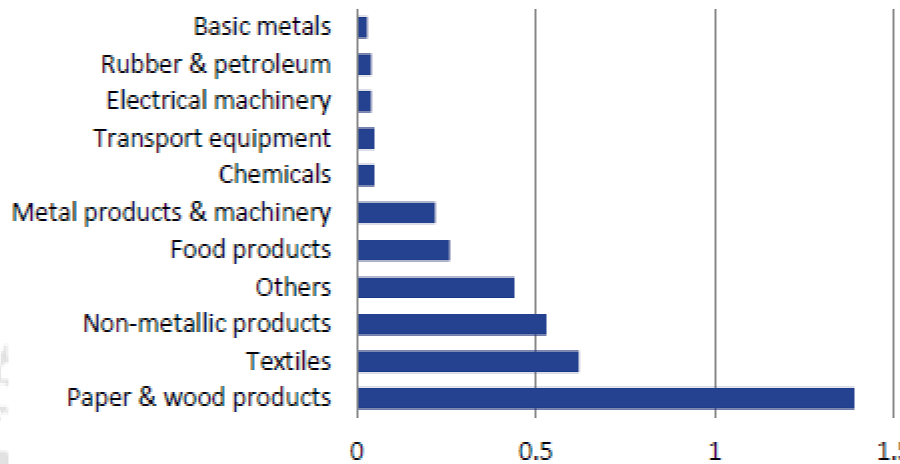


Figure 2.3: Labor intensity across the manufacturing sector in India for 2008 (Number of workers / INR hundred thousand of output generated)

Source: CII-BCG Report on manufacturing-2010; ASI; CSO; Aranca Research;

Paper product has declined in demand due to digitization. Similarly, wood products are replaced by plastics product. Last few decades, there has been tremendous growth in the invention of materials, causing less demand for the wood product.

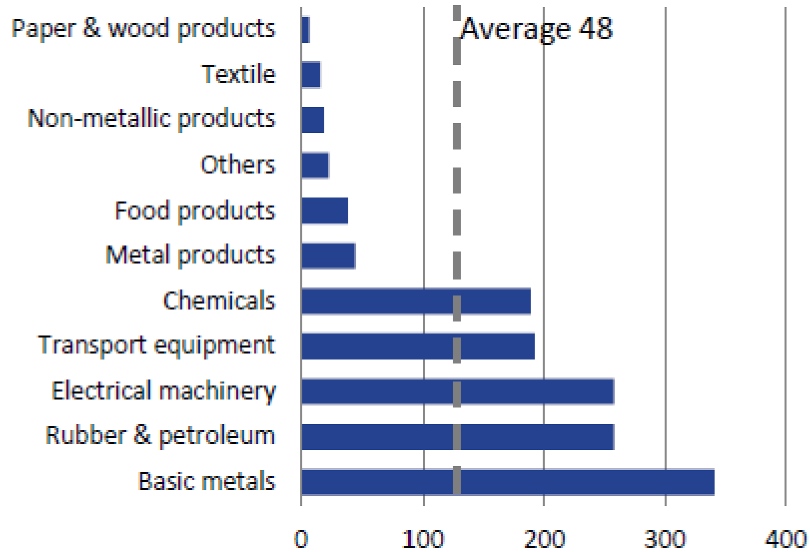


Figure 2.4: Labor efficiency by segment (revenues in INR 10 million/1000 workers)

Source: CII-BCG Report on manufacturing 2010; RBI; MoSPI; Aranca Research

The average capital efficiency (revenue/investment) across sub-sectors of the manufacturing sector varies from 1.4 (Non-metallic products) to 3.5 (Food Products). It is 1.9 for Textile products, which shows that it can generate more revenue than other manufacturing domains with less investment.

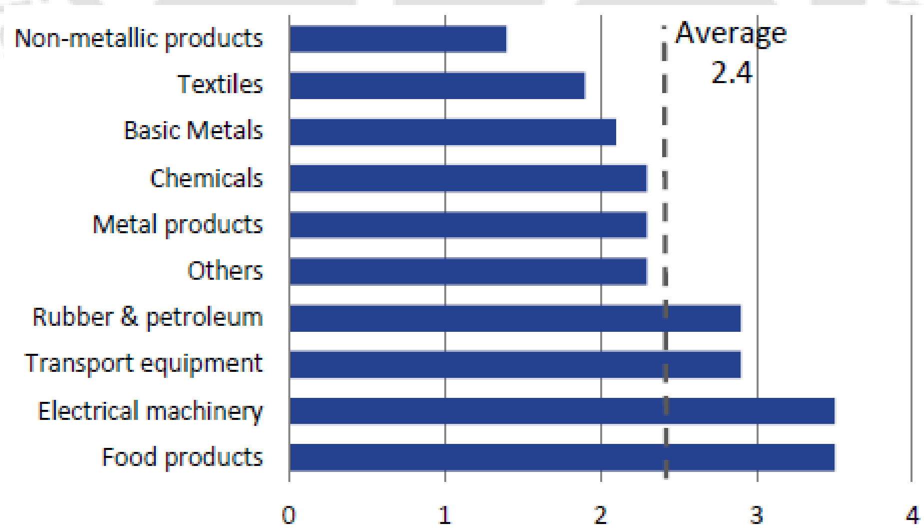


Figure 2.5: Capital efficiency by segment (revenue / capital invested)

Source: CII-BCG Report on manufacturing 2010; Aranca Research

2.2 Textile Industry

2.2.1 Worldwide textile and apparel market

"The Textile & Apparel trade was worth USD 773 billion, in 2013, and is expected to grow at a compound annual growth rate of 5% over the next decade. The details can be seen in Table 2.4 [20]".

Table 2.4: Market size of different countries in the textile sector in 2013

Sl. No.	**Country**	**Million-dollar**
1	European Union-27	355
2	US	230
3	China	165
4	Japan	110
5	Brazil	60
6	India	46
7	Russia	45
8	Canada	30
9	Australia	25
10	Rest of World	80
	Total	1146

In India, textile consumption in 2011 and 2012 was 29881 million meters and 31636 million meters, respectively [21].

"India's lowest per capita spending is on apparel among these markets (USD 37).

Australian per capita spending on apparel is the highest, with USD 1131. If we compare, Indian people spend only 4% compared with Australian per capita spending on apparel. Worldwide per capita spending on apparel can be seen in Figure 2.6 [20]".

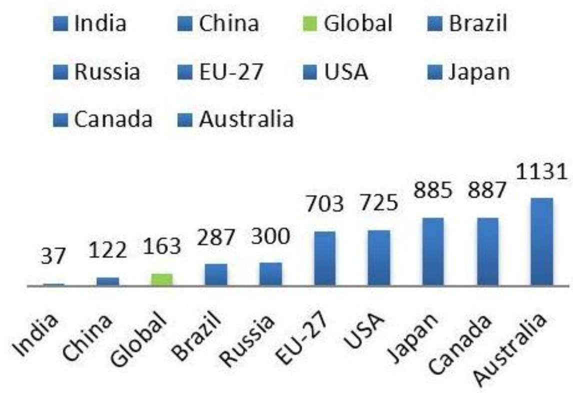


Figure 2.6: Worldwide per capita spend on Apparel in 2013 (In USD)

Increment in income vs. share of consumption

"In lesser developed economies, consumer's spending is highest on food followed by clothing, housing, and other items.

In developed economies, the share of basic categories such as apparel reduces as the consumer's disposable income increases. In contrast, new categories like entertainment, recreation, consumer durable, travel, etc., increase.

This aggregate behavior causes per capita spending on clothing to rise faster initially and slow down later as income increases [20]".

Textile Machinery (all type handloom, power loom etc.) manufacturer globally

"The textile machinery hubs like China, Germany, Italy, Switzerland, and India have already in gigantic competition to craft and bid best technologies in textile machinery.

The success of the modern industry of world textiles is mainly dependent upon continuing significant investment in innovation and invention.

Global Industry Analysts, Inc.(GIA) has declared that the global bazaar for textile machinery is estimated to reach USD 22.9 billion by 2017; demand for sophisticated machines that produce high-quality clothes is increasing whatever the technology, the machine's versatility, and flexibility greatly influence the purchasing decision, and price offers.

Critical factors for dynamic growth in the textile machinery market include economic revival post-recession, rising demand for the nonwoven disposable textile product, increasing demand from promising regions, especially Asia-pacific, and increasing demand for environmentallyfriendly fibers. This article analyzes some of the world-leading textile machinery manufacturing countries.

China & India are developing as major production hubs, whereas Germany & Italy are showing constant Growth in textile machine manufacturing.

China, Japan &Switzerland are also come up with new technologies.

Leading exporters in global textile machinery exports can be seen in Figure 2.7 [20]".

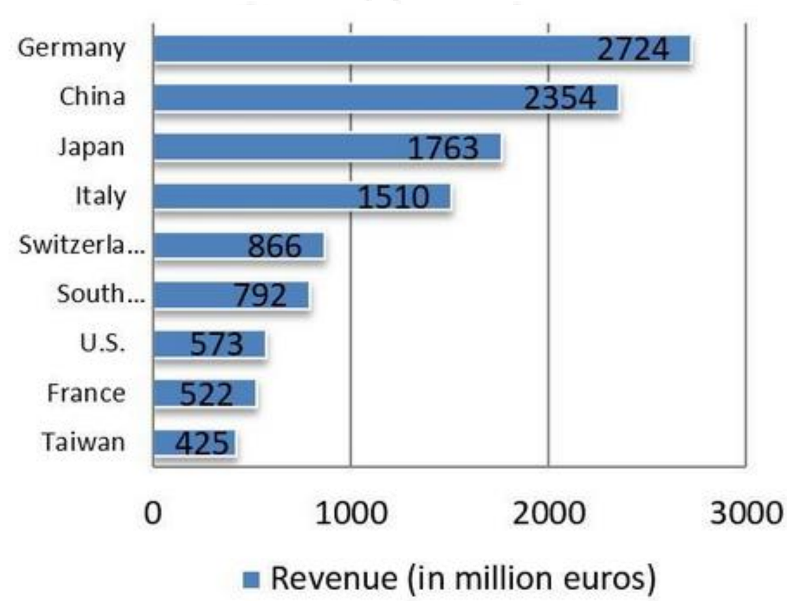


Figure 2.7: Leading exporters in global textile machinery exports

2.2.2 Indian Textile Industry

There is a National textile policy- 2000 for the sector's overall growth. The vision is to produce cloth of good quality at acceptable prices to meet the growing needs of the people, achieve sustainable employment and economic growth, and increase the share of the global market. Also, the objective is to sustain and strengthen the traditional knowledge, skills, and capabilities [22]. It is expected that by 2020 Indian Textile Industries will rise from 70 to 220 billion US$. (President, MANTRA, Surat)

2.2.2.1 Competitive strengths of the Indian textile and apparel industry

- "India has an extensive fibre base

  Natural fibre – cotton (3rd largest in the world)

Man-made fibre – Polyester fibres and filament fibres (5th largest in the world) and

- Cellulosic fibres and filament yarns (3rd largest in the world)

- India is the world's 2nd largest textile producer (after China) and is diversified and capable of producing various textiles. The spinning segment is relatively modernized and competitive, accounting for about 20% of world cotton yarn exports.
- India's textile and apparel industry benefits from a large pool of skilled and inexpensive workers [23]".

2.2.2.2 Policy support to the textile and apparel industry by the Ministry of Textiles, Government of India

- "100% FDI (automatic route) is allowed in the Indian textile sector
- Under Union Budget 2015-16, the government has allocated USD39.81 million for integrated parks in India
- Free trade with ASEAN countries and the proposed agreement with European Union will boost exports.
- Last week, announced for 13000₹ million investments on skill development for 0.9 million employment in textile sector by Ministry of Textile, Government of India [24]".

2.2.2.3 Competitive weaknesses that have impeded the growth of India's textile and apparel industry

- "Policies of the Government of India (GOI) favoring small firms have resulted in the establishment of a large number of small independent units in the spinning, weaving, and processing sectors, discouraging investments in new manufacturing technologies, and limited large-scale manufacturing.
- Production costs of small-scale units have lower than the mills, use a low level of technology, and produce primarily low value-added goods of low quality that are less competitive globally
- India's textile industry depends heavily on domestically produced cotton. Dependencies on rain and contamination levels of cotton are two significant problems with cotton production in India. In India, the cotton ginning quality is poor, causing defective textile products.

- Lack of product specialization is the major weakness in the Indian apparel sector, along with a limited fabric base, which has limited India's apparel production and exports to low value-added goods.
- India has high energy and capital costs, multiple taxation, and low productivity, all of which add to production costs. As a result, textile and apparel products from India are less competitive than those of China and other developing countries in the international market [23]".

In the 12th Five year plan, the objectives were to achieve an annual average growth rate of 11.5% in volume terms in cloth production and 15% in value of exports [25]. Niti Aayog in 2016 said that the demand for all labor-intensive sectors depends on export markets. This statement is also supported by the experience of Bangladesh, Mauritius, Madagascar, and Cambodia. It also suggested that the industry's growth depends on the investors' attributes and mostly the quality and effectiveness of government policies [26].

The percentage share of handloom in the total production of cloth in India is steady at 11-12% based on 2010-2016[27].

2.3 Yarn pre-spinning process and spinning

Raw materials like Cotton, silk, and wool go through various process to make fibre.

2.3.1 Raw Cotton to Lint of cotton

Ginning is a cleaning or separation process from raw dry cotton (5-10 % moisture) to Lint of cotton (35% of raw cotton) by separating the seed (55% of raw cotton) and trash (10% of raw cotton) shown in Figure 2.8.

Figure 2.8a: Raw cotton

Figure 2.8b: Seed of cotton

Figure 2.8c: Trash of cotton **Figure 2.8d: Lint of cotton**

Figure 2.8: Raw to Lint of cotton

Eli Whitney invented the modern ginning machine in 1794. The modern ginning machines can separate up to 230000 Kg lint and bale per day compared to the manual workforce, which hardly made half kg of lint cotton per day. There are two types of ginning technology, i.e., roller ginning and saw ginning. Majority of areas, ginning is done on the farm itself.

Figure 2.9: Bales (Compressed lint of cotton)

One bale generally has 227 kg of weight. Spinning and other processes are done from bales as shown in Figure 2.9 to get the cotton yarn.

2.3.2 Raw silk to silk yarn

The silk-related activity comes under the **Sericulture industry**. Silk yarns are used mainly to make luxury fabric. Silk is famous for its luster, lightweight, resilience, and extreme strength. One filament of silk is stronger than steel of the same size. Nylon and polyester-made yarn are two low-cost alternative yarns to silk. Japan is the first country to raise scientific silkworm. Types of thrown or twisted silk yarn are thrown singles (single thread used mainly for weft yarn), Tram (two or more threads used mainly for weft yarn), Organzine (used for warp of heavy fabric), Crepe (similar to organzine), grenadine, sewings. Soaking, winding (radial winding- for lighter thread and axial winding – for heavier thread), doubling, twisting, and conditioning/steaming are throwing processes. Yarn preparation can be done by coning (used for the knitted machine), copping, and quilling (similar to copping). Reeling is an essential process in this. Cocoon producers are called farmers. Silk twisting units are available in Bangalore, whereas Assam, West Bengal, and Banaras use hand twisting machines.

Reeling

It is done by the producers of raw silk, spun-silk industry, silk throwing, and twisting industry, and silk weaving industry mainly from Karnataka, West Bengal, Tamil Nadu, Andhra Pradesh, Assam, Bihar, Chhattisgarh, Gujarat, Jharkhand, Madhya Pradesh, Uttar Pradesh, Uttaranchal and Jammu, and Kashmir.

"Charkha raw silk" means raw silk reeled from silkworm cocoons with the help of an instrument not worked by power.

"Filature raw silk" means raw silk reeled from silkworm cocoons with the help of any instrument worked by power. This industry is called the **Filature silk industry.**

"Spun silk" means silk yarn spun from pierced or spoilt cocoons, fluff from cocoons, pieces of silk, noils, or other silk waste.

Japan, China, Italy, India, Spain, and France use quality silk yarn to make the finest silk fabric. China produces 85% of the world's raw silk and exports 50% of total raw silk export worldwide.

Breeding

"Central Silk-worm Seed Testing Laboratory" means the Central Seed Testing Laboratory established.

"Pure races" means silk-worm breed or variety maintained through reproductive silk-worm seed with features true to the parents.

2.3.3 Raw wool to wool yarn/worsted yarn

Worsted was made from the long-staple pasture wool from sheep breeds such as Teeswaters, Old Leicester Longwool, and Romney Marsh. Pasture wool was not carded; instead, it was washed, gilled, combed (using heated long-tooth metal combs), oiled, and spun. When woven, worsteds were scoured but not fulled.

Worsted Spun requires a very different fibres preparation and spinning technique. While woolen spinning is all about trapping air, worsted does the opposite. Instead of carding the fibres, they are combed. Hairs are aligned to be parallel instead of being rolled up perpendicular to the direction of the yarn.

Above raw fibres are going through the spinning process to make yarn. Hand spinning is done through Charkha or a manual spinning wheel. Automatic spinning is done through the Blowroom process, Carding, Combining, Drawing, Roving, Spinning, and Cone winding process.

2.4 Fibre and yarn production capacity

2.4.1 Global position of India in Raw materials primarily used in the textile industry

India is very rich in the availability of raw materials for the textile industry. Raw material-wise global position can be seen in Table 2.5. The cost of raw materials is higher in India compared to the World-price [28].

Table 2.5: Global position of India in Raw materials primarily used in the textile industry

Cotton	2nd largest cotton and cellulosic fibres producing country in the world
Silk	India is the second-largest producer of silk and contributes about 18% to the total world raw silk production
Wool	India is the third-largest sheep population in the world, having 61.5 million of sheep, producing 45 million kg of raw wool and accounting for 3.1% of total world wool production. India ranks 6th amongst clean wool producer countries and 9th amongst greasy wool producers
Man-made fibre	India is the 4th largest in synthetic fibers/yarns globally.
Jute	India is the largest producer and second-largest exporter of jute goods.

Source: Confederation of India Textile Industry (CITI)

2.4.2 Fibre production in 2015-16

"Raw cotton – 5746 million Kg. Production in India on 2015-16

There are three types of Synthetic fibre as below:

Polyester staple fibre (PSF) – 893.95 million Kg. Production in India on 2015-16

Acrylic staple fibre (ASF) – 106.81 million Kg. Production in India on 2015-16

Polypropylene staple fibre (PPSF) – 4.7 million Kg. Production in India on 2015-16

Cellulosic: Viscose staple fibre (VSF) – 341.91 million Kg. Production in India on 2015-16

Total fibre production in 2015-16 is 1347.37 million Kg. in India [29]"..

The world is moving to consume fibre 35:65 (Cotton: MMF) in favor of MMF, led by new developments and innovations in MMF and the processing of MMF fabrics. Whereas India's consumption ratio of cotton: MMF is 60:40, compared to China's 20:80.

2.4.3 Ginning, Spinning, weaving, dyeing, and finishing

Indian Cotton Ginning Industry is the second largest in the world. About 36.5 and 38 million bales were ginning during 2012-13 and 2013-14, respectively, in about 1500 modern and 2500 semi-modern ginneries [30].

"India has the second-largest yarn-spinning capacity in the world (after China), accounting for roughly 20 percent of the world's spindle capacity. India's spinning segment is fairly modernized; approximately 35to 40 percent of India's spindles are less than ten years old. During 1989-98, India was the leading buyer of spinning machinery, accounting for 28% of world shipments. India's spun yarn production is accounted for almost entirely by the "organized mill sector", which includes 285 large vertically-integrated "composite mills" and nearly 2500 spinning mills.

Just to Yarn production in 2015-16

<u>Spun Yarn:</u>

Cotton – 4137.83 million Kg. Production in India on 2015-16

Blended – 972.5 million Kg. Production in India on 2015-16

100% Non-Cotton - 554.79 million Kg. Production in India on 2015-16

Total Spun yarn production in 2015-16 was 5664.93 million Kg. in India.

<u>Man-made-filament yarn:</u>

Viscose Filament yarn - 45.41 million Kg. Production in India on 2015-16

Polyester Filament yarn – 1068.8 million Kg. Production in India on 2015-16

Nylon Filament yarn – 37.26 million Kg. Production in India on 2015-16

Polypropylene filament yarn - 12.66 million Kg. Production in India on 2015-16

Total Man-made-filament yarn production in 2015-16 was 1164.13 million Kg. in India

So, total yarn production in 2015-16 was 6829.06 million Kg. in India [31]

The latest price of all types of yarn with their spinning mill name is updated regularly [32]. This information can be referred to buy yarn to verify the price. Also, the weaver can contact the respective spinning mill directly in case of purchasing yarn in bulk. This information will surely help the infant entrepreneur to arrange yarn for weaving in case of shortage.

2.5 Yarn

Hand spinning was practiced in free time after agricultural activity for weaving in handloom. Later, hand spinning almost declined, and handloom weavers started using mill spun-yarn. The handloom sector suffered severely due to interruption in yarn supply by the mills during World War I and II. So, people started hand-spun yarn again in 1945 and used Khadi bhandar run by All India Spinners to distribute the yarn.

Availability of all counts of yarn for different use is not available. Handloom uses the coarsest yarn from waste cotton to finest silk, artificial silk, Tasar silk, and mercerized products. This problem can be solved by doing home spinning or government spinning centers across the country to get the desired count of yarn or availability of such yarn in the nearby area. Yarn remains after mill consumption is distributed to the handloom sector and causes raw material shortage. There should be a proper synchronization between handloom and power loom sectors in terms of yarn distribution. Also, spinning mils do not produce the fine count yarn required by the handloom sector. Uneven distribution of spinning mills to produce yarn across India is another problem. The high cost of yarn is due to the multiple intermediaries between spinning mills and weavers. Coarse yarns are useless in handloom. Twenty-eight percentage handlooms were using woolen silk and artificial silk yarn during independence. These handlooms also started using cotton yarn, as woolen, silk and artificial silk yarn were used for defense services during World War II. Use of various type of yarn can be seen in Table 2.6.

Table 2.6: Sourcing of Hank yarn, dyed yarn, dyes, and chemicals by Handloom worker households

Source	Sourced goods		
	Hank yarn	Dyed yarn	Dyes and chemicals
Open market	76.6%	49.7%	58.1%
Master weavers	8.4%	35.3%	18.9%
Co-operative society	6.7%	8.3%	13.4%
National / State handloom development corporation	1%	1.2%	2.9%
KVIC / KVIB	0.3%	0.5%	0.8%
Others	7%	5%	6%

The sources of supply cotton yarn are 1) Indian mill yarn, 2) Imported foreign yarn, and 3) Handspun yarn

The open market is the dominant source of purchasing hank yarn (76.6%), dyed yarn (58.1%), and ‘dyes and chemicals (49.7%).

Cotton 1 to 20 yarns is used by 30.4% of weavers.

Cotton 21 to 80 yarns is used by 27.5% of weavers.

Cotton 80 and above yarns are used by 9.3% of weavers.

Distribution of various yarn usage with top 3 states can be seen in Table 2.7.

Table 2.7: Distribution of various yarn usages with top 3 states using each yarn

Type of yarn	Handloom worker households (3144839)	Top 3 states using the yarn
Cotton 1 to 20	30.4%	Assam (57.7%), West Bengal (10.9%), Tripura (7.5%)
Cotton 21 to 40	14.7%	Assam (46.9%), West Bengal (17.2%), Uttar Pradesh (8.8%)
Cotton 41 to 80	12.8%	Assam (51.4%), West Bengal (14.2%), Arunachal Pradesh (8.7%)
Cotton above 80	9.3%	Assam (37.4%), West Bengal (31.8%), Tamil Nadu (9.3%)
Viscouse & blends	0.5%	Assam (38.7%), Tamil Nadu (21.2%), West Bengal (19.9%)
Muga silk	4.3%	Assam (30.6%), Manipur (28.7%), West Bengal (14.1%)
Eri silk	2.2%	Assam (48.4%), Manipur (10.4%), Arunachal Pradesh (9.2%)
Mulberry silk	3%	Andhra Pradesh (35%), Tamil Nadu (20.6%), Telangana (8.9%)
Tasar silk	0.9%	West Bengal (27.8%), Assam (19.9%), Jharkhand (12.7%)
Linen	1.4%	Assam (76.8%), Meghalaya (6.3%), West Bengal (4.9%)
Wool	7.9%	Assam (43.5%), Manipur (11.6%), West Bengal (7.4%)
Acrylic wool	2.1%	Manipur (54.3%), Assam (20.2%), Mizoram (9.8%)
Polyester & blends	2.6%	Assam (58.5%), Manipur (14.9%), Nagaland (7.5%)
Jute	0.5%	West Bengal (49.7%), Uttar Pradesh (13.7%), Assam (10.2%)
Zari	2.5%	Andhra Pradesh (33.4%), West Bengal (20.2%), Uttar Pradesh (8.8%)
Others	5%	

2.6 Dyes production capacity

Dyes are of two types

i) Azo (toxic) free dye (Reactive dyes and Most vat dyes)

ii) Natural dyes (Extracted from vegetables and minerals)

The fabric processing (dyeing and finishing) sector, the weakest link in India's textile supply chain, consists of a large number of small units located in and around the power loom and handloom centers [23]".

It has been observed that weaving, dyeing, and finishing are the bottleneck stages in the working cycle. Therefore, considering our capability, we have focused on the weaving stage.

In cone and bobbin form, yarns are dyed for industrial use using high-pressure dye. The handloom sector dyes the yarn in hank form and then processes it to the following processes.

From the famous Benares silks to Kanjeevarams in the south, **cheap imitations** have robbed handloom identities. In addition, easy access to synthetic dyes has meant that natural indigo and alizarin have been replaced by chemical complements, which are then passed off as natural dyes. Take the famous Ikat saree from Karnataka, which used natural indigo for its rich blues and greens and natural material for black color. They use only synthetic dyes now. The reduction in the cultivation of indigo is one of the chief factors. In Bagru block printing, although natural materials like madder, indigo, pomegranate rind, and turmeric are still used, they are replaced by **synthetic supplements for easy availability** and use. Ajrakh printing from Gujarat and Rajasthan was similar though the colors from Gujarat were supposed to be brighter due to the quality of the water. After the 2001 earthquake in Gujarat, the water quality seems to have changed, affecting the dyeing in Ajrakh printing.

2.7 Pre-weaving processes from yarn to weaving preparation

The yarn has again gone through many intermediate processes as below before the weaving process.

Pre weaving activities are winding, warping, tying and dyeing, sizing, loom setting, and manual card punching. Post weaving activity is calendaring (finishing). Tying and dying help to provide a fabric with rich designs and colors. Sizing provides strength to the fabric. Loom setting is done by giving optimum pressure to yarn to avoid no break in the weave/pattern. Card punching ensures fabric patterns can be woven as planned. Calendaring is done to improve appearance by removing dust or dirt.

Accessories of handloom / Semi-automatic handloom in traditional warping process

2.7.1 Winding wheel

Yarns are available in the cop and cone as shown in Figure 2.10 and 2.11 type of hank form in the market. A hank of cotton or spun silk made from short lengths of waste silk is 770m long. A hank of linen is 270m.

Figure 2.10: Yarn in Cop form **Figure 2.11: Yarn in Cone form (for handloom weaving)**

These yarns are not used directly for weaving due to breakage in between and these yarns are converted into required form to use it in the handloom.

Initially, yarn is winded into a bobbin through a spinning wheel/charkha, as shown in Fig.2.12; then, many bobbins, after winding put into a creel to roll the warp on the warping drum. Further, the rolled warp will be transferred into the warp beam used in the semi-automatic handloom

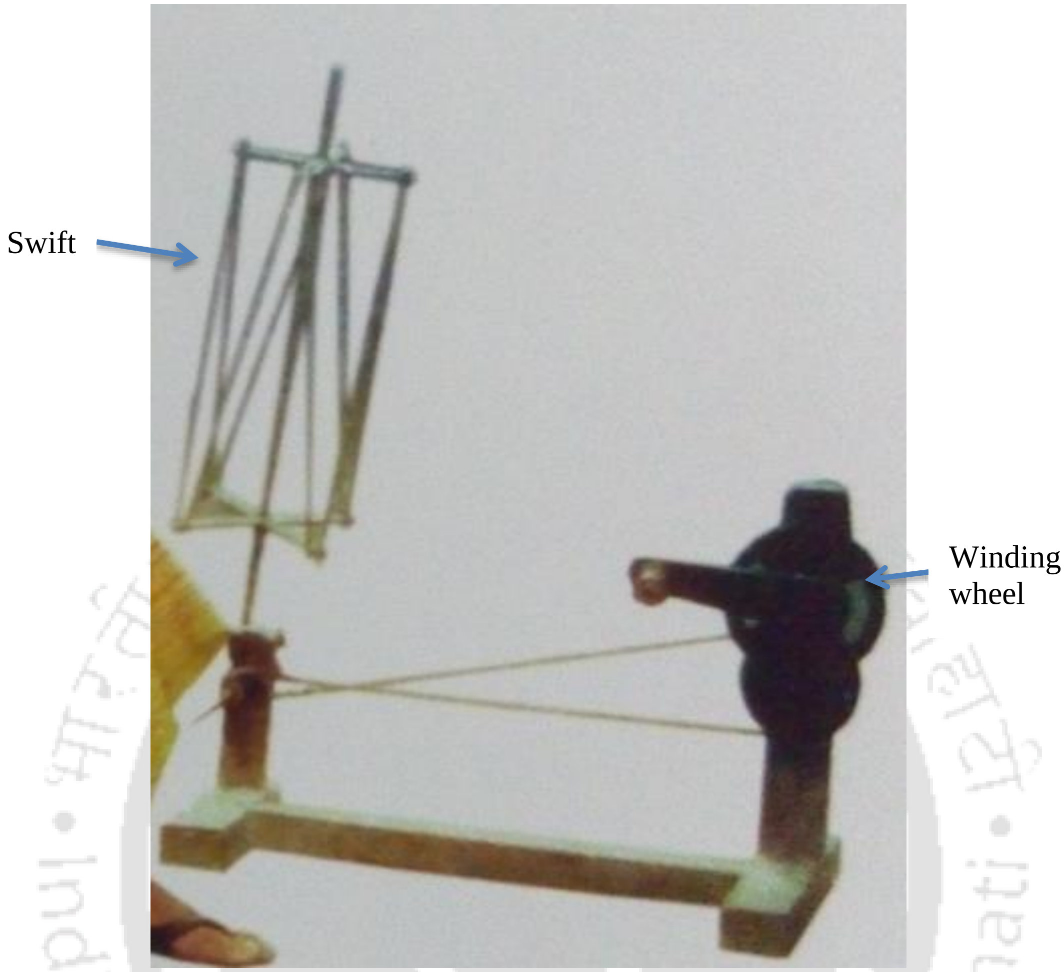


Figure 2.12: Traditional wooden Winding wheel

2.7.2 Creel and Warping drum

Pre-weaving activity plays a critical role in weaving as the output of pre-weaving is input for weaving. The warping drum and creel is to be designed in sheet metal to synchronize between pre-weaving and post-weaving activities properly. Earlier, this process was very tedious, as below Figure 2.13 to 2.15. Warp yarns were lying on the ground, requiring much space to do this activity. Therefore, yarn wind directly from the hank to the warp beam.


Figure 2.13a: Warp entangle in manual warping **Figure 2.13b: Traditional Warping method**

Figure 2.14: Pre weaving activity - 1 on Warp beam[15]

Figure 2.15: Pre weaving activity - 2 on Warp beam[15]

The following way is to do warping with bobbins, wooden creel, and sectional warping drum to wind warp in a warp beam. Improvement over traditional warping process is by using warping drum shown in Figure 2.16 to 2.21.

Figure 2.16: Bobbin used in warping[15]

Figure 2.17: Wooden creel used in warping[33]

Figure2.18: Wooden hack frame between creel and warping drum used in warping[33]

Figure 2.19: Wooden warping drum used in warping - 1[33]

Figure 2.20: Wooden warping drum used in warping - 2[33]

Figure 2.21: Set of Creel and Warping drum with warp beam[34]

2.8 Handloom products and their production

Traditional textiles if India is of two types based on process, i.e., Khadi and Handloom product. Khadi clothes are hand woven with hand-spun yarn made of natural fibre. Handloom clothes are hand woven with all kinds of hand and machine-spun yarns.

Following are the major fabrics with their type of intricacy to weave and produce.

Simple – Dhoti, Sarong, Lungi, Angavastram, Gamcha, Towel / Napkin, Duster, Bedsheet, Furnishings, Blanket, Long cloth, suiting, shirting, Others (Including bandage), Durries, Rugs, Mats

Medium - Jacquard, Dobby, Single Ikat, Silk, Cotton (Thread count above 80+)

Complex – Jamdani, Double Ikat, Patola, Paithani, Pashmina, Buti / Tilli (extra weft), solid border (3 shuttle loom)

Above fabrics with their producing states are given below in the tabular form in Table 2.8.

Table 2.8: Distribution of production of major fabrics

Major fabric	Major producing states	Share of overall production
Saree (0.683 million handloom worker households, i.e., 22.9% of total households)	West Bengal	35.3%
	Tamil Nadu	15.6%
	Andhra Pradesh	13%
	Assam	7.8%
	Tripura	7%
Shawls, Mekhla, Chadder, Loi, stole, scarf, muffler (0.797 million handloom worker households, i.e., 26.7% of total households)	Assam	77.4%
	Manipur	4.9%
	Arunachal Pradesh	4.6%
	Nagaland	3.7%
	Meghalaya	2.3%

Angavastram, dhoti, sarong, lungi (0.580 million handloom worker households, i.e., 19.5% of total households)	Assam	42.6%
	Manipur	19.1%
	Tripura	11.1%
	Arunachal Pradesh	5.7%
	Tamil Nadu	4.1%
Towel, napkin, duster, gamcha (0.491 million handloom worker households, i.e., 16.5% of total households)	Assam	72.4%
	West Bengal	12%
	Manipur	4.2%
	Meghalaya	2.9%
	Tripura	2.2%
Durries, rugs, mats (0.101 million handloom worker households, i.e., 3.5% of total households)	Uttar Pradesh	46.8%
	Assam	12.7%
	Haryana	9.4%
	Uttarakhand	4.5%
	Himachal Pradesh	4.5%
Dress material (Salwar, kameez, etc.), suiting, shirting, long cloth (0.095 million handloom worker households, i.e., 3.2% of total households)	Assam	23.6%
	Manipur	17.3%
	Tripura	13.2%
	Chhattisgarh	9.7%
	Andhra Pradesh	5.6%

Bedsheet, furnishings, blankets (0.101 million handloom worker households, i.e., 3.4% of total households)	Assam	26.8%
	Tamil Nadu	20.1%
	Manipur	14.5%
	Uttar Pradesh	7.1%
	Karnataka	7%
All others, including surgical bandages (0.127 million handloom worker households, i.e., 4.3% of total households)	Assam	27.5%
	West Bengal	19.3%
	Manipur	13.1%
	Tamil Nadu	10.2%
	Uttar Pradesh	4.2%

Singh O P and Sood S (1989) mention in Textile trends, No-2, 1989 that Carpet, cotton, and silk (muga and mulberry, etc.) sarees, temple curtain, muga, and mulberry silk sarees, patchwork, lungis, sarongs, bedsheets, towels, etc. are main product mix of handloom[35].

The glory of handloom products in history

Cloth of gods, Jataka tales, other early Pali texts, and calendered fabric in the Gupta empire's period shows in history interesting details of weaving techniques before the 6th century B.C.. From the Akbar period onwards, zari and brocades flourished for the Mughal and Rajasthani paintings. Also, turbans were a high-volume product with zari work in the Mughal period. Veils or long scarves were identified in the eighteenth and nineteenth centuries. Kundigar Zala locality in Banaras was famous for its ornamentation capability in weaving from ancient times. In the mid-seventeenth century, Banaras was exporting gold or silver zari textiles worldwide and was well known for its best quality. George Viscount Valentia, a British travel to Banaras. His remarks on close pattern brocades are costly to wear only on special occasions. After that, many British people came and made a report on Banaras weaving. Dupattas, scarves, sarees, silk dhotis, and brocades of different silk designs were produced in Banaras based on a government report in 1965. Varanasi (specially Madanpura and Ahaipur mohalla), Azamgarh (Mubarakpur), Mirzapur (Rajgadh, Chetgunj, Narayanpur, Jamalpur, Seekhad, Majua), Gopigunj and Sewapuri in Bhadohi (Sant Ravidas Nagar), Chandoli (Sahabgunj, Chakiya, Barhani, Mugalsarai, Sahupuri, Fatehpur, Chandauli, Shikargunj), Chunar and Chakia are weaving hub in and around Varanasi. Badi Bazar, Nati Imli, Lathapura, Philkhann, Chittanpura, Ram Nagar, Lohta, Chiragaon, Baburi, Baragam, and Ashapur areas in Varanasi are equally famous with Madanpura for their experiment with existing and new innovated technique and design[36].

Common Handloom product

Even though weavers can weave many designs and different fabrics but weavers focus only on one or two varieties like saree (63%), dress material (26%), and shirting (5%) only[37]. It might be possible that Weavers may not get regular customers through ornamentation or customized new design. Quick service is impossible through this route as a customer must wait for the desired design to weave by the artisan/weaver. Sometimes, it will also be challenging to fulfill the excess demand than capacity due to a lack of inventory[38].

Varanasi is world-famous for brocade sarees and dress material. Banarasi sarees are made of silk warp and silk weft, on plain/satin ground/base brocaded with extra weft patterns in different layouts introducing buties, bells, creepers, buttas in the ground, border, and anchal for getting glamorous appearances.

As per the data in the above Table 2.9, it is clear that the handloom sector is in more trouble compared to the Mill or Power loom sector. The compound annual growth rate is negative. The target compound annual growth rate is also lower than all other segments. The cloth production ratio between handlooms to power loom is almost 1:5+. The involvement of the workforce is too high in the handloom compared to the power loom. Textile industries in Bangladesh also have similar problems, which can be improved by introducing better technology; also, the cost of production will be high due to obsolete technology, therefore insisting on using modernized equipment [39]. In India, the committee of the Kanungo report recommends a solution for the handloom sector that the entire handloom sector will be converted into the improved (semi-automatic) handloom or the decentralized power loom industry [40].

A successful small-scale entrepreneur needs a sound political environment, access to market, infrastructure, and capital [40]. A clear definition of small and tiny industries is essential as traditional small and modern small industries are not the same. Government should ensure that the released fund has reached the intended person; releasing funds for the development is not enough [41].

The mill sector does all pre-loom and post-loom activity. Sometimes it also does weaving in the loom. A power loom is for weaving with external power, and a handloom is for weaving manually.

The segmented share of cloth production is shown in Table 2.9 with a compound annual growth rate [42].

Table 2.9: Trends in Segmented share of cloth production (in Million sq. m.)

Item	2001-02	2011-12	CAGR%	Projection for 2016-17 as per current CAGR	Targeted CAGR for the next 5 years (percent)	Projection for 2016-17 as per the targeted CAGR	Share in total cloth production	Employment share (in million) in total cloth production
Mill Sector	1546	2313	3.73%	2778	6	3095	3.83%	
Handlooms Sector	**7585**	**6901**	**-0.86%**	**6609**	**3**	**8000**	**11.42%**	**4.331**
Powerloom Sector	25192	37445	3.67%	44839	10	60306	61.94%	6.436
Hosiery Sector	7067	12946	5.66%	17049	12	22815	21.41%	
Others (Khadi, Wool & Silk)	714	848	1.58%	917	4	1032	1.40%	
Total Cloth Production	42104	60453	3.34%	71246	7	84788	100%	

Source: Textile Commissioner, Mumbai

The handloom sector contributes nearly 15% of the cloth production in the country and contributes to the export earnings. 95% of the world’s hand-woven fabric comes from India [43]”.

‘India Handloom’ brand and Handloom mark have been introduced to provide the customer with an authentic handloom product.

“The “India Handloom” brand is given only to high-quality, defect-free, authentic handloom products for catering to the needs of consumers looking for niche handmade products.

The Handloom mark was launched to guarantee the buyers that the handloom products being purchased by them are genuine hand-woven products and not power loom or mill-made products [43].

Import of Handloom products by India from 2009 to 2015 has been shown in Table 2.10.

A drastic reduction of 66.6% in imports of handloom products was observed in 2016-17 compared to 2015-16 [44].

A three-month training program on improved handloom weaving under the “IIFCL-NSTFDC Skill Upgradation and Economic Empowerment of Tribal Handloom Women Artisans in the NE states “Project for the state of Arunachal Pradesh was successfully concluded on 10th July 2015 in Diyun, Changlang Dist., Arunachal Pradesh. Mr. Hemanta Rabha, Sr. Project Officer, IIE, informed that IIE implements this project in all the North-Eastern states covering 200 schedule

Table 2.10: Import of Handloom Products by India in a million USD

Items	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	(April –Dec.) (P)	
								2015-16	2016-17
Mill									
Cotton	1465	1604	1724	1684	1622	1592	1504	1134	1139
Blended	482	526	521	674	818	808	733	551	532
Man-Made Fibre Fabrics	69	75	68	60	91	86	78	56	54
Total	**2016**	**2205**	**2313**	**2418**	**2531**	**2486**	**2315**	**1741**	**1544**
Handloom									
Cotton	5857	5973	6021	6239	6315	6427	6827	5020	5299
Blended	137	143	121	115	145	88	106	79	83
Man-Made Fibre Fabrics	812	791	759	598	644	688	705	523	630
Total	**6806**	**6907**	**6901**	**6952**	**7104**	**7203**	**7638**	**5622**	**6011**
POWERLOOM									
Cotton	10128	11883	12027	13955	14320	15241	15696	11752	11730
Blended	5487	5853	6302	6655	7117	7511	7826	5829	5994
Man-Made Fibre Fabrics	21382	20279	19116	17428	15353	14997	13462	10105	9173
Total	**36997**	**38015**	**37445**	**38038**	**36790**	**37749**	**36984**	**27686**	**26896**
HOSIERY									
Cotton	11464	12258	10798	11992	13256	13699	14413	10571	10788
Blended	1661	1756	1524	1838	1982	2042	2144	1596	1557
Man-Made Fibre Fabrics	577	620	624	711	961	1153	1090	885	757
Total	**13702**	**14634**	**12946**	**14541**	**16199**	**16894**	**17647**	**13052**	**13103**
ALL SECTORS									
Cotton	28914	31718	30570	33870	35513	36959	38440	28477	28956
Blended	7767	8278	8468	9282	10062	10449	10809	8055	8165
Man-Made Fibre Fabrics	22840	21765	20567	18797	17049	16924	15335	11568	10614
Total	**59521**	**61761**	**59605**	**61949**	**62624**	**64332**	**64584**	**48101**	**47735**
Khadi, Wool, Silk.	812	798	848	843	876	944	921	691	691
Total	**60333**	**62559**	**60453**	**62792**	**63500**	**65276**	**65505**	**48792**	**48426**

tribe women artisans (25 from each state). In his addressed, Mr. D. Gadi, Extra Assistant Commissioner (EAC), Diyun urged all the trained weavers to take up handloom weaving seriously to earn a decent livelihood. He asked trainees to make diversified products with their traditional design so that the products get market outside the state. Steel Frame looms has also been distributed to all the 25 nos. of trainee along with certificates [45].

How the Modi government is planning to make Varanasi the hub of handloom products?

"The government is serious about linking fashion and modern designs to handloom," says SK Panda, Union textiles secretary. Shantanu Nandan Sharma | ET Bureau | March 08, 2015, 09:26 IST

Despite the mounting odds on the handloom, some weavers in Varanasi still resist the migration to the power loom. A few families like Ram Lal Maurya's of Bazar Diha locality in the city are unwilling to experiment with new designs by reputed designers. Maurya, for example, is a fourth-generation weaver who sells only heavily embellished Banarasi sarees. He quotes a fixed price of ₹75,000 for one saree. The price has no bearing on bookings, with all his ten looms booked for the next six months (one handloom costs about ₹15,000). He avoids the gaddedar route, selling directly to a limited set of clients based in Kolkata, Mumbai, and Ahmedabad. The product is couriered, and money is transferred electronically through banks.

"Our clients are ready to pay us a good amount even as we have been using just one design for over three decades. Our only experimentation has been a change of colors. Why will we embrace a new design if the existing one works well?" asks Maurya. His designs, called Nilambari, Shetambari, Pitambari, etc., are one design with different hues.

The small crowd problem is that such weavers are a minority. The government firmly believes that only linking market-driven modern designs with handloom can save traditional handloom weaving in Varanasi and other clusters (See box on Other Handloom Hubs). In January, a national workshop on promoting handloom in fashion was held on NIFT's campus in Bhubaneswar, Odisha. Officials said it was a great beginning. The government has now decided to do this workshop promoting handloom with fashion. In this annual event, one NIFT campus will actively involve weavers of the nearby handloom clusters. Handloom workers working with yarn shown in Figure 2.22.

Figure 2.22: Hank Dyeing

"We are planning to digitalize traditional handloom designs and create a brand for high-value handloom cloth," says Secretary Panda, explaining a series of initiatives to revive the handloom sector. In August last year, the development commissioner for handlooms, under the aegis of the textile ministry, joined hands with online retailer Flipkart India to provide an online marketing platform and market intelligence to boost Indian handloom weavers. "Through this exclusive agreement, Flipkart will provide an online marketing platform to weavers in India. This platform will support data analytics and customer acquisition as infrastructural support to help weavers to get remunerative prices for their products and scale up their business,". Seven months later, online sales, particularly the high-valued handloom products, are faltering. "Customers are still unwilling to spend ₹ 5,000 or ₹ 10,000to buy a handloom saree. That is why we want to bring in the Handloom India brand," Secretary Panda says.

After plain weaving, there is possibility to do ornamentation through embroidery, block-printing, and roller printing. The small fabric can be printed in block printing, whereas more oversized fabric needs roller printing.

Fabric defects in handloom

The defect is an unwanted structure on the fabric due to many reasons. The following are some fabric defects, e.g., missing ends, missing picks, reed mark, double end, weft crack, weft bar, temple mark, starting mark, float, and slubs. Some important defects are shown in Figure 2.23.

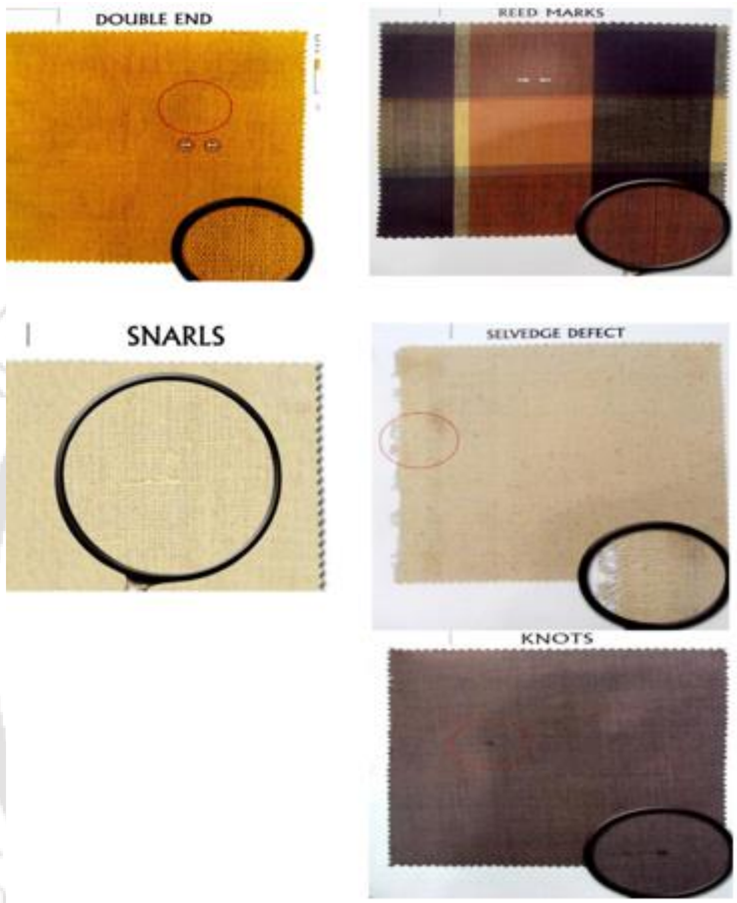


Figure 2.23: Fabric defects

Fabric defects are elaborated with respect to appearance, cause and prevention shown in Table 2.11.

Table 2.11: Fabric defects

Name	Appearance	Cause	Prevention
Thick Place in the weft direction	Bars of denser woven fabric across the cloth	Cloth roll take-up and let off warp rolls not done properly	Cloth inspection
Floating End	Un-woven warp end	1 End not drawn into heald 2 Broken heald	Cloth inspection
Slubs	Thick lumps of yarn weft way	1 Faulty weft yarn 2 Not removing broken weft correctly	Cloth inspection Good methods
Wrong dent	Thin line warp way in the cloth	End or ends are drawn into the wrong dent	Know the correct denting order
Wrong draft	Irregular patterns warp way in the cloth	End or ends are drawn into the wrong heald	Know the correct drafting order
Broken pick	Visible line weft way in the cloth	1 Broken weft not wholly removed 2 Loose pick not found	Always use correct weft repair methods. Cloth inspection
Double pick	A thick line runs across the cloth	1 Not having found the loose pick 2 Wrongly wound weft in the pirns	
Thick Place weft way	Thick bar in weft way	1 Double weft running in 2 Thick/wrong weft yarn	Correct weft in the pirn

(Source: Textile committee reports)

Remedial measures for controlling the defects

Defects can be reduced by using good quality yarn, good weaving preparations; proper loom settings at various stages of fabric manufacturing

Precautionary measures

Back of Loom (Warp Beam)

Slubs: A thick place in the warp: slubs in the warp yarn sheet can cause problems when passing through the heald wires or beater. Once spotted, it is the weaver's responsibility to remove it, avoid warp breaks if the slub does not pass the reed; or avoid a fault if the slub goes into the cloth.

Extra end: Guide it through the guide eyes to the winding device.

Missing end: Take the nearest extra end and guide it through the guide's eyes to the missing end position.

Crossed end: Correction to be made by the weaver.

Thick end or wrong yarn count: Take a guide to the winding device, identify the end as incorrect with a label, and replace it with a normal end from the extra end reserve.

Stuck ends/sizing fault: Separate the ends with the help of the guides.

Spare end bobbin: The extra ends provided on the warp roller must be guided through the guides provided on the spare end bar to the side of the loom and then wind onto the spare end bobbin. These need to be kept tidy; otherwise, a tangled mess will quickly result. When the bobbin is complete, it needs to be stripped.

Fluff and fly: When pieces of fluff or fly have settled on the warp, they should be removed immediately to prevent them from being woven. Fluff and flies accumulating on the loom should be removed before it becomes detached and woven into the cloth.

Waste / wild yarn: Extra pieces of yarn, either left on warp roller/ sheet or dropped onto a loom, needs to remove before they become entangled or woven in.

Contingencies

Front of Loom (Cloth Beam)

Cloth Quality

Short picks: Is the weft being appropriately inserted?

Weft bars: Is this a variation of weft, or improperly operated take-up of woven fabric, or let-off dead weight.

Uneven yarn: Has the weft quality deteriorated, and the pirn needs to be changed?

Broken pick: Has the weft been inserted for the whole width of the cloth, either breaking in its insertion or not being held at the receiving side?

Double-end: Two ends weaving as one in the same heald break out the extra end.

Wrong draft: An end or ends have been inserted into the wrong heald eye, resulting in a break in the cloth pattern.

Wrong dent: An end has been drawn incorrectly in the reed resulting in a warped line down the cloth or a break in the cloth pattern.

Selvedge: Is the selvedge complete and correct, resulting in a right edge to the fabric? Is the selvedge construction correct?

Reed Marks: Does a damaged beater cause any warp way lines?

2.9 Cost of handloom product

Input like yarn etc. costs 50 to 80 percent of the product cost, and labor cost varies from 15 to 23 percent as per Table 2.12.

Table 2.12: Input cost and labor cost of some handloom products

Handloom product	Input cost like yarn etc.	Labor cost
Colour saris (80s x 80s)	67%	33%
Dhotis (120s x 110s)	36%	64%
Dhotis (20s x 20s)	60%	40%

The All India handloom board also recommended that there should be a central marketing organization with branches in Bangalore, Bombay, Kolkata, Lucknow, and Amritsar. Central marketing organization is to find markets, create demand, arrange direct transactions between parties, and finally find possibilities to explore possibilities for further development. Also, Central Museum is proposed in New Delhi and showrooms at various centers.

Marketing and research committee (First Meeting) January 1946 recommends that the Government of India employ Marketing officers to promote the marketing of handloom products overseas at various locations across the globe.

Sales of handloom products

The local market (64.1%) is the primary source of sales for overall handloom products.

Jagadish Das & Co, a wholesale dealer of Banarasi sarees based in the Chowk market area of Varanasi, has been in the handloom business for over 100 years [46]. Source of sales of handloom products can be seen in Table 2.13

Table 2.13: Sources of sales by handloom worker households

Sources of sales	Share of sales
Local market	64.1%
Master weavers	17.6%
Co-operative society	8.8%
Organized fairs	1%
Export	0.4%
E-commerce	0.2%
Others	8%

IKEA has tied up with many small local companies like Rangsutra craft Pvt. Ltd., New Delhi. Hence handloom products have found their way to the plush European markets. Many small enterprises and big labels like Hermes online store, USA, are working with artisans from Indian villages to create unique apparel.

Growth and expansion of this handloom product market have not been able to reflect on the traditional handloom industry in India concerning growth in overall fashion retail on e-commerce and online. As per the Handloom Export Promotion Council, exports of Indian handloom products were $357.58 million in 2016-17, $353.92 million in 2017-18, $343.43 million in 2018-19, $315.62 million in 2019-20, $222.65 million in 2020-21, which is extremely low compared to other types of clothes/textiles which are being exported from India[15].

Competition in export

Two Asian countries, Bangladesh and Vietnam, have comparable apparel exports, whereas Cambodia and Ethiopia are new emerging significant players within the next decade [47].

14% to 18% export of Man-made textiles compared to Total textiles from 2007 to 2012.

The export of various textile products has shown in Figure 2.24. This is shown as per fibre used.

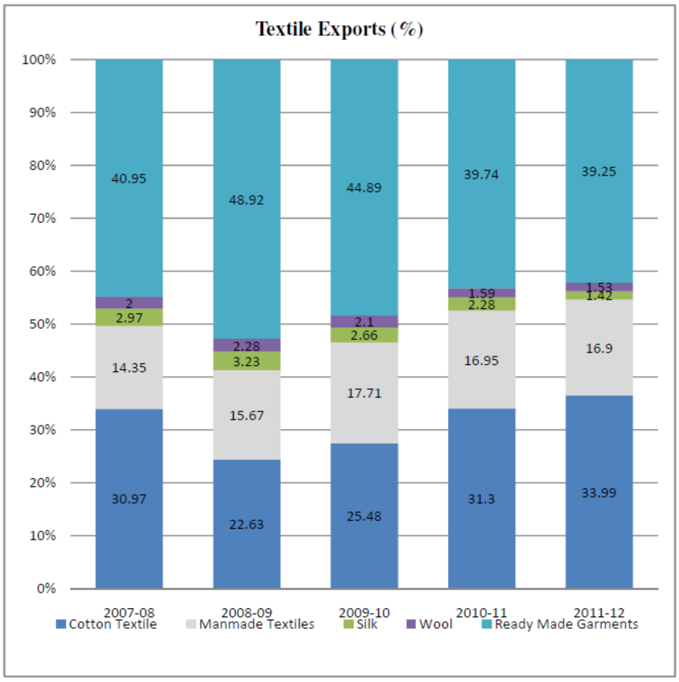
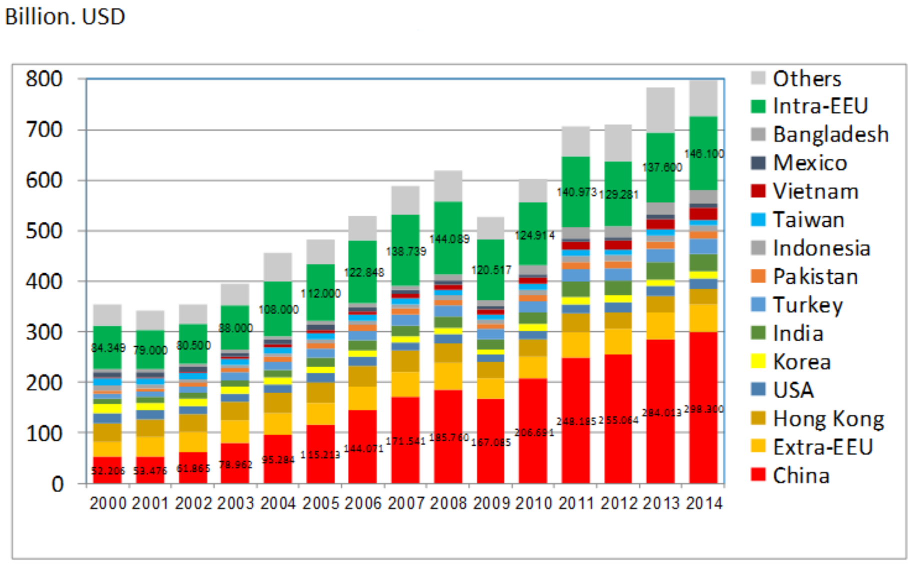


Figure 2.24: Export of various Textile products

(Source- Foreign Trade Statistics of India (Principal Commodities and Countries) DGCIandS, Kolkata (2012)

Countrywise export of textiles and clothing has shown in Figure 2.25.



Quelle: World Trade Organization, International Trade Statistics

Figure 2.25 Export Textiles and clothing 2000 - 2014

Strong growth forecast, the buoyant housing market, strong social mobility, young population, home textiles, and staple products are the contrasting factors shaping the future of the regions, i.e., Asia Pacific, Middle East, and Africa, compared to North America, Australia, Western and Eastern Europe.

Year-wise Production of Handloom cloth & export of handloom products is in Table 2.14.

“Exports of Handloom during 2009-10 were of the order of USD 265 million and increased to 365 million in 2010-11, recording a growth of 38%. During 2011-12, Handloom exports further increased to US$ 554 million, recording a growth of 60%. The biggest destination of India’s Handlooms products is the USA, followed by the UK, Italy, Germany, France, Australia, Japan, Netherland, UAE, and Spain during FY 2015-16[27].

A Buyer Seller Meet (BSM) was conducted in North Eastern Region to promote sells [48].

Handloom products of 46.6 ₹ million have been sold through e-commerce [43].

Export Promotion Activities of the Handloom Export Promotion Council (HEPC) organize India International Hand-woven Fair (IIHF). Also, HEPC has been periodically organizing awareness seminars across the country about the intricacies involved in export trade.

Table 2.14: Year-wise production of Handloom cloth & export of handloom products

Year	Handloom cloth production (million square meters)	Handloom exports (₹ in million)
2007-08	6947	NA
2008-09	6677	NA
2009-10	6806	12528.1
2010-11	6907	15749.5
2011-12	6901	26239.6
2012-13	6952	28119.7
2013-14	7104	22331.1
2014-15	7203	22464.8
2015-16	NA	23533.2
2016-17	NA	23922.1
2017-18	NA	22801.8
2018-19	NA	23923.9
2019-20	NA	22483.3
2020-21	NA	16447.8

Limitation to export

Standardization and uniform (ends and picks) quality of handloom products is the most significant problem for export in this decentralized sector. Standardization will improve by uniform handloom machinery with standard bought-out items like reeds and healds for repeatability and reproducibility of handloom products.

Remedies to overcome limitations to export/increase sales

These products should be made with individual characteristics of color and design to meet local and overseas requirements, primarily to reduce competition with mill products. Also, the products must fulfill the demand of the marketing organization by producing in bulk with improvements in weaving techniques for ornamentation to make a unique selling proposition. Handlooms could not fulfill the bulk requirement, while mills have seized the opportunity. Small power looms are in big competition with handlooms.

Khaddar movement after 1928 changed many clothing habits like the Gandhi cap substituted by a modern cap. Many such substitutions occurred in those periods when handloom products were replaced by modern products woven in automatic machines.

Then Master weavers, co-operative societies, and small-scale industries can be formed to produce in an organized way if proper inputs are available to them, like yarn, and dye, in their desired quantity. These organizations will succeed with adequate financial support, training on management efficiency, maintaining uniform operational costs, and proper marketing strategy. The state government of Assam has decided to separate the Handloom Co-operatives from The Directorates of Handloom and Textiles.

Comprehensive all India study about the structure and production of the industry, the types of weavers and intermediaries, the earnings, the method and cost of marketing, the extent of competition, and co-operative organization is essential to make any action plan.

Investigated the existing method of production like winding, warping, sizing, beaming, and weaving, dying to find possibilities to improve it to fulfill the marketing need.

Some specialty fabrics, namely curtains, furnishings, upholstery clothes, table clothes, towels, etc., are required in bulk as government purchases.

Following products have the highest export in descending order based on overall revenue generated in 2020-21 and also the last ten years' export history

1) Floor coverings
    i) Mat and mattings, including Bath mats, where cotton predominates by weight – ₹ 4788.9 million
    ii) Carpets, Rugs, and mats of handloom – ₹ 2244 million
    iii) Cotton Durries of handloom (including Chindi durries, Cotton chenille durries, Rag rug durries, printed durries, druggets) –₹ 1045.3 million
2) Madeups
    i) Other furnishing articles of handloom – ₹ 2526.8 million
    ii) Cushion cover of handlooms – ₹ 1214.8 million
    iii) Bed sheets and bed covers of handloom – ₹ 1226.8 million
    iv) Terry fabrics, Other bed linen, table linen, toilet linen, kitchen linen of cotton, handloom –₹ 576.4 million
    v) Pillow cases and pillow slips of handloom – ₹ 480.5 million
    vi) Table cloths and table covers of handloom –₹ 284.4 million

vii) Floor cloth, dishcloths, dusters, and the like of cotton of handloom – ₹ 133.7 million

viii) Napkins of handloom – ₹ 81.5million

3) Clothing accessories

i) Scarves, shawls, mufflers, mantillas, veils of silk handloom – ₹ 614.5 million

4) Fabrics

i) Woven fabrics of silk or of silk wastes of handloom – ₹ 621.5million

ii) Other fabrics (Except Saree, dhoti, lungi, terry towel, casement, sheeting (Takia, leopard cloth other than furnishings)) of handloom– ₹ 382.6 million

iii) Sarees of handloom – ₹ 38.3 million

iv) Lungis of handloom –₹ 28.1 million

v) Zari bordered sarees of handloom –₹ 20.8 million

vi) Dhotis of handloom –₹ 12.4million

The product-wise trend in the last ten years is shown in Figure 2.26 and 2.27 to choose the product in demand for export during weaving to increase earnings. Profitability needs to check by reducing activity-based costing from the selling price.

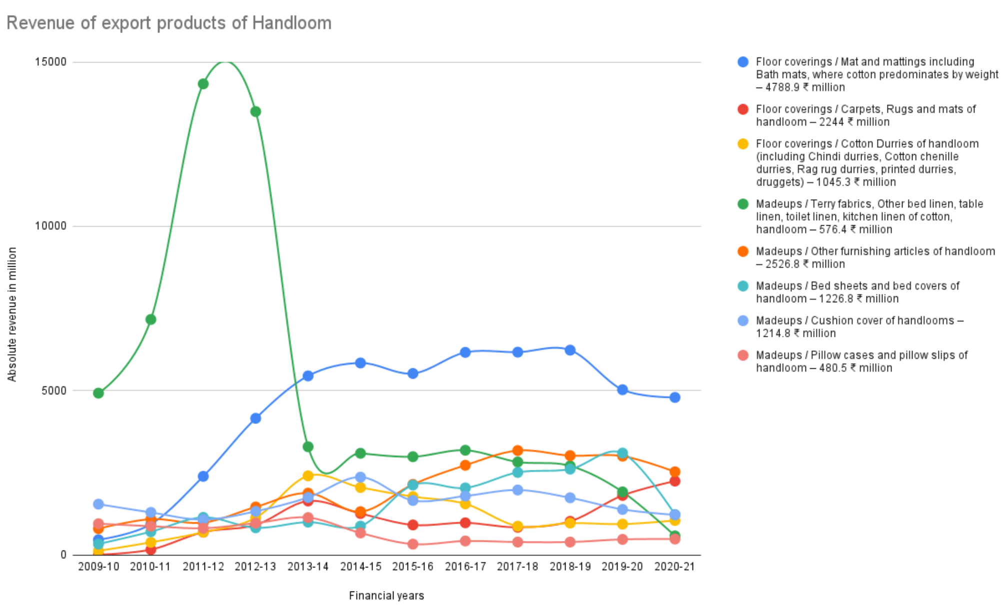


Figure 2.26: Revenue in export of handloom product for last 10-year part-1 of 2

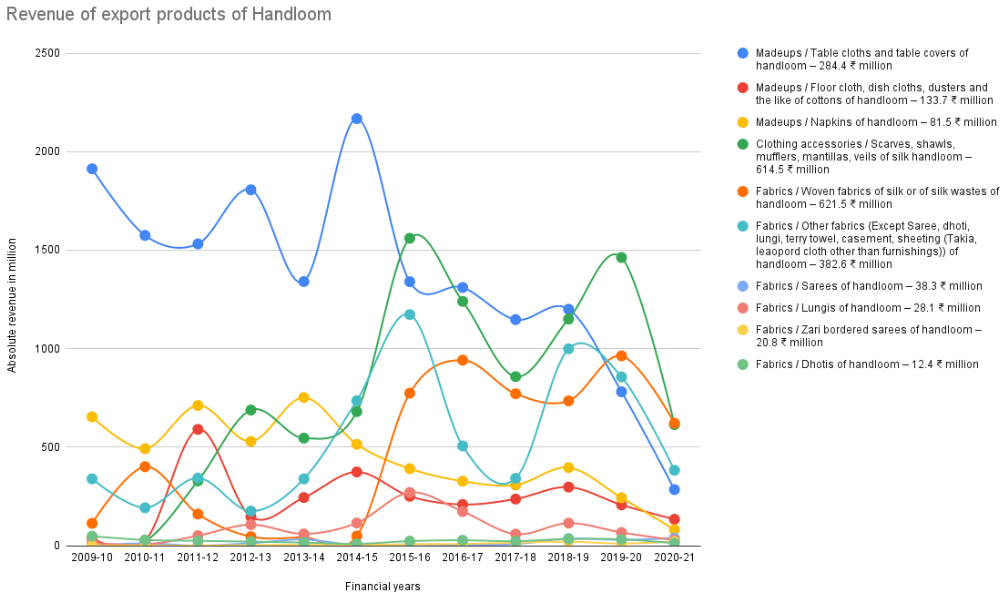


Figure 2.27: Revenue in export of handloom product for last 10-year part-2 of 2

Mat, carpet, rug, other furnishing articles of handloom, woven fabric of silk or silk waste, sarees of handloom, zari bordered sarees of handloom are showing uptrend revenue-wise. Few products show a downtrend only during corona, like bed sheets and bed covers, scarves, shawls, mufflers, mantillas, and veils of silk handloom. It can be checked alternate products supplied by a competitor with their market share for making unique selling proposition through intervention at various levels.

2.10 Present status of handloom weavers

2.10.1 Weaver and Weaver's household

There are a total of 31,44,839 households involved in handloom work, but only 21,78,293 (69.3%) households own a loom in their house, remaining households are involved in allied (Pre and post-weaving) work. These households may not have a complete loom set in their house. Handloom household can be a weaver household, Allied worker household, Master Weaver household with loom, or Idle loom household. Four states account for 1.8 million such households involved in handloom work, i.e., Assam (1.09 million) households, West Bengal (0.34 million), Manipur (0.21 million), Tamil Nadu (0.17 million).

There are 5457 non-household units with 1 22,302 looms and 0.265 million handloom workers. Non-household units are commercial units solely for marketing/sales / wholesale/retail with production-related activities (weaving and allied work). Three thousand two hundred eighty-one of the non-household units (60.1%) have reported idle looms due to lack of market demand (50%), non-availability of weavers (27%), and lack of capital/funds (23%).

Table 2.15: Affiliation of weaver households (2545312) to various economic groups [1]

	Member of any co-operative society	**Member of an SHG / Joint Liability Group**	**Associated with a producer company**
Total weaver households	12.5%	9.9%	3.5%
Benefited from the association	5.8%	2.1%	1.7%

There are 26, 73,891 (75.9%) weavers and 8 48,621 (24.1%) allied (Pre and post-weaving) workers, out of which 6, 37,870 allied workers are working in 5, 99,527 allied households, and 2, 10,751 allied workers are working in 1, 72,911 weaver households among total 35, 22,512 handloom workers working in handloom sector in India. Nearly 72% of weavers are women in India. Also, higher numbers of females are involved in handloom's allied activities. There were 2.4 million full-time and part-time weavers during independence. Only 2.4% weavers of age group 14 – 18 years are engaged, indicating the shallow interest of young generations in these activities. Affiliation of weaver's household to various economic group can be seen in table 2.15. Gender wise weavers is shown in Table 2.16 with their employer.

The average number of handloom weavers per household is only 1.22 among the total households that own loom in their house. Shallow involvement among the family members shows that this sector partially fulfills household needs only to follow their ancestors' tradition, with not much commercial motive involved.

Table 2.16: Distribution of weavers (2673891) by gender and employer category

	Independent	**Under co-operative society**	**Under KVIC / KVIB**	**Under Master Weaver**	**Under SHDC**
Male	59.5%	11.8%	0.4%	27.5%	0.8%
Female	85.8%	4.1%	0.2%	9.5%	0.4%

The average handloom allied workers per household are only 0.48 among the total households does not own a loom in their house. It shows that 52% of the household's allied work (pre-and post-weaving activity) own loom in their house. Pre weaving activities are winding, warping, tying and dyeing, sizing, loom setting, and manual card punching. Post weaving activity is calendaring (finishing). Tying and dying help to provide a fabric with rich designs and colors. Sizing provides strength to the fabric. Loom setting is done by giving optimum pressure to yarn to avoid no break in the weave/pattern. Card punching ensures fabric patterns can be woven as planned. Calendaring is done to improve appearance by removing dust or dirt. Gender wise allied workers is shown in Table 2.17 with their employer.

Table 2.17: Distribution of Allied workers (848621) by employer category

	Independent	**Under co-operative society**	**Under KVIC / KVIB**	**Under Master Weaver**	**Under SHDC**
Allied workers	56.8%	6.5%	1%	34.6%	1.1%

50.8% of handloom workers (weavers and allied workers) work full time, and the remaining 49.2% work part-time. There are 75.6% of male workers from urban areas work full time whereas only 36.5% female workers work full time in this sector.

Part-time and full-time weavers count not shown in the census in table 2.18

The census does not show the number of handloom weavers by employment typology count in Table 2.18

The person day per weaver (per year) is 208 days, and allied worker (Pre and post-weaving work) (per year) is 205 days. The top five states with the highest 'average number of person-days of work are Maharashtra (310), Andhra Pradesh (302), Delhi (292), Chhattisgarh (290), and Puducherry (286). This data shows that states with fewer looms are engaged most of the time in the year.

To understand the employment category among handloom workers are as below. It will help to understand the sector in terms of their organization.

Table 2.18 shows that only 6.7% of handloom workers worked in the organized sector, where 70.3% of units dominate by cooperative societies, mostly by Assam (31.3%), Tamil Nadu (14.7%), Nagaland (11.7%), Uttar Pradesh (7.9%), and Kerala (5.9%).

Co-operative societies are of two types, i.e., Apex societies and Primary societies. Apex society is an umbrella body of Primary society.

Table 2.18: Number of handloom workers by their employment typology

Employment type	Number of handloom workers	Number of looms
Independent	2577044 (73.2%)	2.685 million
Under Master weaver	684060 (19.4%)	0.016 million
Under co-operative society	223414 (6.3%)	0.122 million
Under Khadi & Village industries commission (KVIC) / board (KVIB)	15144 (0.4%)	
Under State handloom development corporation (SHDC)	22850 (0.6%)	
Total	3522512	

There are 10456 Master Weaver households among the total weaver households. A total of 10623 weavers are working in these Master weaver's households. This kind of organized weaving is primarily observed in Assam (10009), West Bengal (413), and Karnataka (171). Workers of organized handloom units used to do full-time jobs. Part-time work is done majorly by independent handloom workers. Urban area (49%) is more organized than rural area (18%) through co-operative society, under Khadi and Village Industries Commission (KVIC) at the national level / Khadi and Village Industries Board (KVIB) at the state and union territory level or with State Handloom Development Corporation (SHDC). Four states where weavers are more organized in nature, i.e., Goa (95%), Puducherry (91%), Kerala (71%), and Tamil Nadu (56%).

Table 2.19: Number of handloom worker's households by income[1]

Income (in ₹)	Number of household of handloom workers
Less than 5000	2109525 (67.1%)
5001-10000	824021 (26.2%)
10001 – 15000	140509 (4.5%)
15001 – 20000	29989 (1%)
20001 – 25000	17467 (0.6%)
25001 – 50000	19738 (0.6%)
50001 – 100000	2863 (0.1%)
Above 100000	727 (0.02%)
Total	3144839

The income of handloom workers varies widely from 0 to approximately 0.1₹ million per month. These spreads can be noticed in Table 2.19. Low earning is due to very few weavers focused on ornamentation and many weavers do weaving to fulfil household need.

Top 6 percentile households only earn above the minimum wage rate defined for agriculture, i.e., 11160₹, which is the lowest among all in the unskilled category. Lower 94 percentile households can replicate the best practices in operation or marketing, followed by the top 6 percentile households. In three states, more than 60% of weaver households have earned more than 5000₹ per month. Those states are Goa (95.5%), Uttarakhand (69.8%), and Maharashtra (60.3%). The average number of person-workdays is also highest in Maharashtra i.e. 310 days a year.

It has been found that independent weavers and weavers working in co-operatives earn slightly more than the weavers working under master weavers [49].

There are some non-household handloom units. Non-household handloom units are with a shed/area and have looms. These units have their name on the signboard with their primary affiliation/registration. There are 5457 such units; most are cooperative societies (70.3%), followed by others (13.6%). This kind of unit is found majorly in Assam (31.3%), Tamil Nadu (14.7%), Nagaland (11.7%), Uttar Pradesh (7.9%), and Kerala (5.9%). There are 195111 handloom workers, and 122302 looms in these 5457 non-household units. There are 116724 looms in working condition and 37053 looms in an idle condition out of a total of 122302 looms in non-household units. Five thousand five hundred seventy-eight looms are rejected out of total looms in non-household units.

2.11 Type of weaving

Following are the types of weaving

Structural weaves

1) Plain weave
2) Rib weave
3) Basket weave
4) Twill weave
5) Herringbone weave
6) Satin weave
7) Sateen weave
8) Leno weave
9) Oxford weave

10) Bedford cord weave
11) Waffle weave
12) Pile weave
13) Crepe weave
14) Lappet weave
15) Tapestry weave
16) Striped weave
17) Chequered weave
18) Double cloth weave

Jacquard weaving with extra warp/weft

Dobby weaving for ornamental weaving

2.12 Traditional handloom weaving machine

A loom is a weaving machine having at least three primary motions, namely, shedding, picking, and beating up, and two secondary motions, namely take up and let-off motions. In a loom, intermittent movements to healds, shuttle, sley, and some other parts are required, and all the parts must be accurately adjusted to ensure a regular sequence during weaving. A loom is termed a 'handloom' when it is actuated by human power without using any motor.

Three handloom types are generally used in India, namely, Primitive or throw-shuttle loom, Fly-shuttle loom, and Semi-automatic loom. The fly-shuttle looms are divided into two classes: Fly-shuttle pit-loom and Fly-shuttle frame-loom or four-poster fly-shuttle loom.

Traditional loom can be of Throw –Shuttle Handloom and Loin loom type in North-east region. An advanced Loin loom is shown in Figure 2.28.

Figure 2.28: Loin Loom

In this loin loom, the material woven is of plain weave structure. Concise warp length of 1 to 2 pieces of fabric of their use, like a shawl, bag, scarves, etc., of less than 50 cm, is woven each time. In the absence of reed, fabric woven has very high warp density and is predominant over weft, warp ends are visible, and weft picks are hidden. Because of this, there is no color dilution like fly-shuttle handloom due to the presence of reed, and resultant interlacement of warp ends & weft picks regulated by reed count. Material woven in loin loom is very compact, thick, and durable. A solid extra weft design can be imparted. It is ergonomic, and both upper and lower limbs are used and more productive. Traditional weavers can weave without any retraining with existing skills, Fabric produced are at par with loin loom. A traditional loin loom is a low productive, tedious, primitive handloom that uses the weaver and upper limbs loom for weaving. Loin loom requires beat-up two to three times to correctly set the weft with the fall. The fabric of more than 0.5 to 0.6 meters is challenging to weave in a loin loom. Some diversified traditional handlooms used in India can be seen in Figure 2.29 to 2.37.

Figure 2.29: Wooden frame fly-shuttle handloom without jacquard at Handloom development research centre, Ambari, Guwahati

Figure 2.30: Wooden frame fly-shuttle handloom with jacquard at Handloom development research centre, Ambari, Guwahati

Figure 2.31: Wooden frame fly-shuttle handloom with jacquard at ARTFED, Guwahati

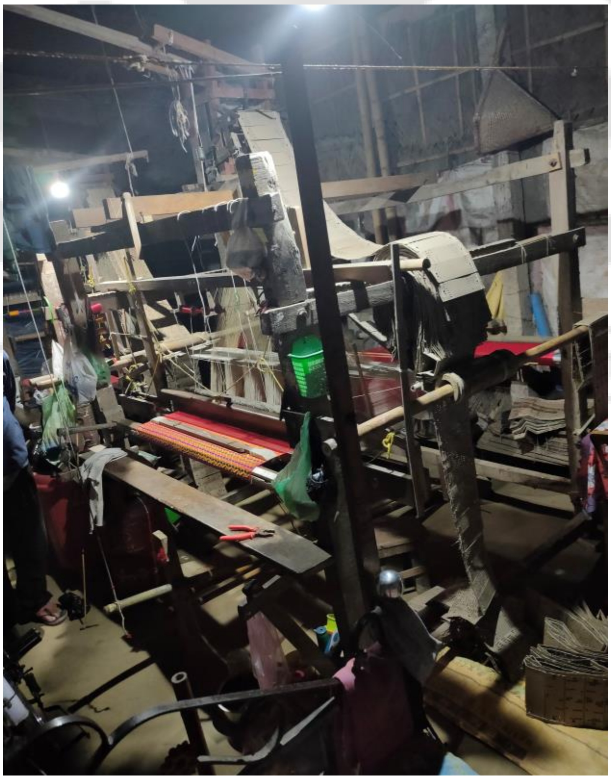


Figure 2.32: Wooden frame fly-shuttle handloom with jacquard at Sualkuchi, Assam

Figure 2.33: Metal frame fly-shuttle handloom at Handloom development research centre, Ambari, Guwahati

Figure 2.34: Metal frame fly-shuttle handloom with dobby at Handloom development research centre, Ambari, Guwahati

Figure 2.35: Bamboo frame through-shuttle handloom at Handloom development research centre, Ambari, Guwahati

Figure 2.36: Wooden throw-shuttle pit handloom at Handloom development research centre, Ambari, Guwahati

Figure 2.37: Jack and Lam loom with front side pivot

Figure 2.38: Extra warp handloom with terry towel weaving capability

The loom shown in Figure 2.38 uses an extra warp for ornamentation. This loom can weave terry bath towels.

Double jacquard can be used for extra warp and extra weft design, as shown in Figure 2.39. One jacquard is used for an extra warp and the other for an extra weft.

The jacquard attachment is used for continuous extra weft ornamentation like a border in fabrics like saree. Deepak Bharali's chaneki (2008 patented) is used with the jacquard for making buta using an extra weft. Extra weft insertion device like Dipak Bharali's buta machine shown in Figure 2.40 is used for inserting the extra weft, but shedding is still through jacquard.

Figure 2.39: Double jacquard mounted on a single loom

Figure 2.40: Buta machine with sley in handloom

“There are 2.377 million looms in India, spread across the household and non-household units. Off all looms, 58 percent are frame looms (4 percent dobby/jacquard, while the majority 54 percent are other frame looms), 26 percent are pit looms (15 percent with dobby/jacquard and 11 percent are other pit looms), 13 percent are loin looms, 1 percent are pedal looms, and 2 percent are other kinds of looms” [2]. Loin looms are one type of primitive loom in which all weaving motion is operated by hand. Pedal looms are semi-automatic looms in which only shedding motion is operated manually, but there is no provision to fix jacquard for ornamentation. In an age in which shuttle-less looms can run at 1500 ppm (picks per minute), it is worth noting that shuttle looms running at 110–250 ppm are widely used, particularly in the developing world [7]. Against this speed, the handloom has a maximum of 30 ppm only. Fly-shuttle looms use a mechanism and does not move the shuttle manually; therefore, an average weaver can run a medium-width fly shuttle loom at 80 to 100 picks per minute.

Under the Handlooms (Reservation of Articles for Production) Act, 1985, a handloom has been defined as “any loom other than power loom”; and included 22 items such as pure silk and cotton saris lungis, dress material, and towels. The list was whittled down to 11 items in 1996 [50]. In 2012, a meeting was held to remove handloom weavers' drudgery and make a sustainable engagement in the sector. A new definition of handloom was proposed: “Handloom means any loom other than power loom, and includes any hybrid loom on which at least one process for weaving requires manual intervention or human energy for production’. This change in the definition was opposed by many handloom experts in the

National Consultation on Handloom Sector held on 1st March 2013. Due to this amended definition, there will be no difference between the power loom and the handloom sector. The advisory committee meeting was held on 12th April 2014 to solve this handloom definition and drudgery issue in the handloom sector. Also, it is discussed to know the reasons for attrition in the sector: hard labor for long hours and age-old technology. Therefore, the committee recommended to study handloom and power loom sectors across India before making the final decision on the definition and to examine the feasibility of mechanization. State-wise handloom observed as shown in Table 2.20. These developments were not user-friendly and were not commercialized [9].

Table 2.20: Different types of looms being used in various states

Sl. No.	States	Types of Looms
1	Andhra Pradesh	1. Pit Looms, 2. Raised Pit Loom, 3. frame loom, 4. Malabar frame loom 5. Fly Shuttle Frame looms, 6. Multi treadle frame Looms, 7. Pit Looms Fitted with Dobbies 8. Pit looms fitted with Jacquards 9. Fly Shuttle Frame Loom 10. Semi-Automatic looms
2	Arunachal Pradesh	1. Loin Loom, 2. Fly shuttle frame Loom, 3. Free-standing foot-operated looms called khridha.
3	Assam	1. Loin Loom, 2. Pit Loom, 3. Throw shuttle loom, 4. Fly Shuttle frame loom, 5. Fly Shuttle Frame Loom with dobby 6. Fly Shuttle Frame (Bamboo Loom) 7. Semi-automatic Loom
4	Bihar	1. Fly Shuttle Pit looms 2. Frame Looms 3. Fly Shuttle Frame Loom 4. Fly Shuttle Frame Loom with Dobby

5	Chattisgarh	1. Pit Loom, 2. Fly Shuttle Pit Loom 3. Frame Loom 4. Fly Shuttle Frame Loom 5. Fly Shuttle Frame Loom with dobby
6	Delhi	1. Ordinary Frame Loom
7	Gujrat	1. Pit Looms, 2. Multitreadle pit loom for Mashroo weaving 3. Frame Looms 4. Fly Shuttle Frame Loom
8	Haryana	1. Pit Looms, 2. Throw Shuttle Frame Loom 3. Fly Shuttle Frame Loom 4. Fly Shuttle Frame Loom with Jacquard 5. Wooden frame Loom 6. Punja Durry Loom
9	Himachal Pradesh	1. Ordinary Frame Loom 2. Fly Shuttle Frame Loom
10	J & K	1. Pit Looms 2. Fly shuttle Looms, 3. Kani Pashmina Looms
11	Karnataka	1. Pit Looms 2. Throw Shuttle Pit Loom 3. Fly Shuttle Pit Loom 4. Throw Shuttle Frame Loom 5. Fly Shuttle Frame Loom 6. Fly Shuttle Frame Loom with Dobby 7. Fly Shuttle Frame Loom with Jacquard 8. High raised pit frame loom 9. Multi Treadle Frame Looms
12	Kerala	1. Pit Looms 2. Raised pit looms 3. Pit Loom with Dobby 4. Frame Loom 5. Fly Shuttle Frame Loom 6. Fly Shuttle Frame Loom with Dobby

		7. Fly Shuttle Frame Loom with Jacquard.
13	Madhya Pradesh	1. Traditional Pit Looms, 2. Frame Loom, 3. Fly Shuttle Frame Loom with Jala and 4. Fly Shuttle Frame loom dobby,
14	Maharashtra	
15	Mizoram	1. Loin Loom, 2. Brack strap Loom 3. Burmese Loom (Zoo Loom)
16	Odisha	1. Pit Looms, 2. Raised Pit Loom, 3. frame loom, 4. Malabar frame loom 5. Fly Shuttle Frame looms, 6. Multi treadle frame Looms, 7. Pit Looms Fitted with Dobbies 8. Pit looms fitted with Jacquards 9. Fly Shuttle Frame Loom 10. Semi-Automatic looms
17	Rajasthan	1. Pit Looms, 2. Frame Loom, 3. Fly Shuttle Frame Loom 4. Verticle Panja Durry Loom
18	Tamil Nadu	1. Pit Looms 2. Throw Shuttle Pit Loom 3. Fly Shuttle Pit Loom 4. Throw Shuttle Frame Loom 5. Fly Shuttle Frame Loom 6. Fly Shuttle Frame Loom with Dobby 7. Fly Shuttle Frame Loom with Jacquard 8. High raised pit frame loom 9. Multi Treadle Frame Looms
19	Tripura	1. Loin loom, 2. Brack strap loom, 3. Pit loom 4. Frame Loom,

		5. Chittaranjan loom,
20	Uttarakhand	1. Pit Loom 2. Frame Loom 3 Frame Looms Jacquards 4. Frame Looms Dobby
21	Uttar Pradesh	1. Pit Loom 2. Throw Shuttle Pit Loom 3. Fly Shuttle Pit loom 4. Frame Loom 5. Fly Shuttle Frame Loom 6. Fly Shuttle Frame Loom with Dobby 7. Fly Shuttle Frame Loom with Jacquard 8. Semi-Automatic Loom
22	West Bengal	1. Loin Loom, 2. Fly Shuttle Pit Loom, 3. Throw Shuttle Pit Loom, 4. Fly Shuttle Frame Loom 5. Fly Shuttle Frame Loom with Dobby 6. Semi-Automatic Chittranjan Loom

During the field visit, they found some improvements in looms and their attachments developed by various R&D institutions like IIHTs (Indian Institute of Handloom Technology) and WSCs (Weaver Service Centre) to improve productivity, reduce drudgery, and fatigue of the weaver, as shown in Table 2.21.

Table 2.21: Technological Developments in Handloom/Sectors

Sl. No.	**Name of Loom**	**Attachment**	**Purpose**	**Benefits/advantages**	**Places/where the same is under use**
1	Frame loom with Multi treadles and 4 to 8 Heald shafts	Tie & dye technique	To get front side one design and back side another design in Tie and Dye Technique.	Without any Dobby/jacquard attachment, designs will be produced on both sides	Pochampally, A.P.

				of the Fabric.	
2	Multiple Extra Weft Butta Mechanism	Catch card system	To weave all the buttas in a row simultaneously	Production will increase more than twice, so the weaver will earn more, reducing the strain on the weaver.	Vijayawada, A.P.
3	Ordinary pit looms Multi treadle frame looms. Frame looms Pit looms fitted with dobbies & jacquards.	Jamdani technique	Jamdani sarees, fine-count cotton sarees, dhotis, and Lungies Towels, Bedsheet. PET. Cotton Shirting Fine count cotton dobby sarees, Cotton rich pallow sarees kuppadam solid border sarees	It enhances the variety and ornamentation of design. Weavers wages increased	East Godavari Dist., A.P.
4	Ordinary pit looms. Pit looms fitted with dobbies and Jacquards. Semiautomatic looms.	Semiautomatic looms, only treadling is done manually. The remaining picking and beating are done automatically	Lungies and Plain dress material Fine count cotton rich pallow sarees, Kuppadam solid border rich pallow sarees, fine count dobby border sarees, jacquard dress materials. PET. Cot. Shirting, PET. Cot. Suitings.	Production increased more with uniform picking & beating	A.P.
5	Loin loom & free	The looms	Monpa bag, kop	Production	Tawang in

	standing foot operated looms called Khridha	are versatile, light and can be easily moved in and around	fabric, Nam fabric	increased and wages increased	Arunachal Pradesh
6	Fly shuttle frame loom & throw shuttle frame	Extra Weft Design is prepared with the help of bamboo stick and draw box system	Cotton Mekhala, Chaddar, Gamocha, Bed cover, Curtain cloth	Production is high and at the same time the wages increased.	Jorhat (Titabor, Majuili in Assam State)
7	Kani Pashmina Looms & Fly Shuttle Looms	Jala system	Kani Pashmina & Raffle Shawls, Stoles etc., tweeds, Raffle Shawls, Kani Shawls, Stoles, etc.	Production increased and the wages increased for better living standards	Ganderbal, Pulwama, Shopian in J&K State
8	Charkha	High Speed Cycle Wheel	For winding of bobbins and pirns	Pirns Increase in productivity and decrease in drudgery compared to traditional wooden charkha	Introduced almost all places of India
9	Fly shuttle Frame looms	Double Decker shedding	Reversible furnishing	Increases production from 2 to 2.5	Under Trial

		and picking Attachment		times for earning more wages	
10	Fly shuttle Frame looms	5-wheel take-up motion	To maintain picks per inch for texture of the fabrics. Uniform pick.	To reduce the Physical effort of weaver during weaving. Increase the production.	Maheshwar and other parts of the country.
11	Zoloom (Modified Myanmar loom)	Myanmar loom is more or less similar to semiautomati c loom. Modified loom is manufacture ed within the state by local carpenters.	Mozo traditional Puan in plain, in extra weft designs, shawls, muffler, stoles, shoulder backs, novelty items, made-up, etc. depending on the skill of weavers' even double clothes for furnishing fabrics.	It is extremely mobile and easy to transfer from place to place. When not in use as it occupies a very little space. It also needs less investment as because most of the parts are made from bamboo & wood.	All over Mizoram State mainly Aizawal, Champhai, Mamit, Kolasib, Lunglei, Lawngtlai, Saiha.
12	Fly shuttle frame looms	Double race board loom	To weave two different fabric one over the other with one picking motion	Double quantity of cloth is produced with single picking	Commercial application is not tried

				and beating. Earn more wages	
13	Fly shuttle frame looms	Pick & Pick twin cloth weaving	To weave two cloths side by side with conventional selvedge	Two narrow width fabrics can be woven with selvedge on both the fabrics with provision to insert two different counts in pick and pick	Chennimalai and in around places of T.N.
14	Fly Shuttle Frame Loom	Handloom with jacquard on frame loom/ raised pit loom	Looms with heavy frames & round shape Cloth roller dia 8”-10”	Cotton saree, Art silk saree etc.	Paramkudi, in and around places of RamnadDt, Tamilnadu
15	Chittaranjan loom	Modified frame loom fitted with take-up and let-up motion. Weft inserted rate 80 to 120 picks per minute for plain	Saree, Bed cover, Shirting, Gamcha, Gaze, Bandage, Pachara (Sarong), Chhadar etc.	More production, easy operation of loom and earning more wages	Tara Nagar, Nutun Nagar, Durjoynagar, Jogendranagar Khowai of Khowai dist. Tepania of Gomati Dist. Tripura

		fabric.			State
16	Fly Shuttle Frame Loom. (Handloom for Differently able person or Handloom for Blind person).	The Handloom is fitted with 1. Mechanical Warp stop motion which gives a particular bell sound whenever warp end breaks and stop the sley motion automatically 2. Mechanically weft stop motion which gives other types of bell sound whenever the weft yarn breaks or exhausted and stop the sley automatically	The Handlooms is useful for blind persons to weave simple plain cloth without any defects and earn their livelihood from weaving. By hearing different sounds, the blind person could immediately stop weaving the loom. He can attend to the mending of broken thread and them start weaving the fabric without any defect.	Simple plain cloth without any defects and earns their livelihood by handloom weaving.	Not yet commercial
17	Semi-automatic Chittaranjan Loom	Mala Dobby (60 to 104 lever) used	Dobby design saree, Gamcha, Lungi, Gauz-	Production more and earns more	Nabadwip, Ranaghat, Gangarampur

		for saree weaving	Bandej (Basirhal)	wages with easy operation	in W.B. and other places of the Country

Flying-8 weaving loom by Andreas Moeller is designed to be self-built, inexpensive, and productive. It has been successfully implemented in several countries like Ethiopia, Sierra Leone, Estonia, Haiti, Canada, Uruguay, Germany, and Finland. Loom is made up of locally available wood, fastened by nails. Design and marketing strategy developed by Germany. Technology is named Flying-8 technology [51]

There is a semi-automatic handloom by AVL Looms, USA, where picking takes place through electrical actuators and take-up motion through a standard gear attachment in one of their model. Sensors are used to check complete movement. They are making their loom of wood and ensuring flexibility to design fabric. A-series loom by AVL Looms has hand picking but uses various standard components. Standard branded components increased cost, and the loom was electricity-dependent in the previous case. Therefore, these models will not be suitable in our context [52]

2.13 Semi-automatic handloom

A semi-automatic handloom stands between an ordinary handloom and a power loom; some of its motions are operated by the weaver, while others are mechanically operated. Semi-automatic looms are of several kinds, but the following are commonly used in the industry: Chittaranjan loom, Salvation Army loom, and Hattersley loom.

Figure 2.41: Chittaranjan semi-automatic handloom at Handloom development & research centre, Ambari, Guwahati

The principal characteristics of the Chittaranjan loom shown in Figure 2.41 lie in its synchronous beating up, take-up, and let-off motions, whereas shedding and picking motions are operated similar to the fly-shuttle loom. Major drawbacks of Chittaranjan loom are jerky motion of 5-wheel positive take-up motion and non-suitability of precision control of a fraction of picks. Similarly, the principal characteristics of the Salvation Army loom lie in its synchronous picking, take-up, and terry-motions. The mechanism of terry-motion is to regulate the sweep of a sley to produce terry piles. Hattersley loom acts the same as the power looms except for the movement of the sley and the crankshaft, which may be operated manually or by motive power from the top shaft. In the case of manual operation, more than 1270mm fabric width is difficult to control. Also, 5-wheels take-up provides jerky motion in this loom.

"Previously, a pedal loom was developed to operate by synchronizing the various motions of the loom by pedals incorporating most of the design features of power looms which are very hard to operate. An in-depth dynamic study of various loom mechanisms was done by sophisticated electronic instruments (strain gauge, oscilloscope) to make the loom easy to operate. Picking motion is the major power consumer. The structure of the frame is made from mild steel channels and angles in the new loom. This loom has a cycle-type pedal design to increase leverage. It consists of cycle-type pedals, chain, and sprockets. This loom uses a self-lubricated nylo-cast bearing to reduce friction. A polynomial cam profile is used for the picking mechanism. The shedding mechanism is based on simple harmonic motion consisting of a treadle lever, treadle bowl, and shedding cam. The weight of sley is reduced using sisam wood, aluminum angles, and channels with a flywheel. The prototype loom designed needs 60 percent less leg effort and 35 percent to 40 percent less power than conventional model pedal loom" [53].

"Another study supports the importance of letting-off of the warp and taking-up of cloth to avoid time loss in weaving adjustments by the weaver. A remarkably improved Boku loom in Ghana is redesigned and developed to overcome let-off and take-up mechanism" [54].

Technology and Action group for Rural Development have developed a manually operated loom combining versatility and ease of operation. In this loom, all manual operations existed, but ergonomically improvements were made in the handloom. This loom was 36% more efficient than the traditional loom [55]. Nepal loom is almost like a power loom in a handloom frame, used for jeans material, and lacks ornamentation [56]. A semi-automatic handloom developed by CSTRI of Central Silk Board with automatic take-up and let-off mechanism was found to be too big & heavy [57]. Central Silk Board, Khadi Village

Industries, National Handloom Development Corporation, State Institute for Rural Development, and State Handloom and Weaving Department, like government organizations, are intervening to improve handloom [57]. Shanti loom is made by steel L channel shown in Figure 2.42, but it has a manual picking motion [58]. This loom had the disadvantage of having the same picking difficulties as in traditional handlooms and fabrication and machining due to the shape of L section which required many jigs and fixture for mass production.

Figure 2.42: Shanti loom

It is also observed in the Semi-automatic handloom where the sley swings from the top. In this loom, it is challenging to incorporate a mechanism for take-up and let-off motion (Source: Youtube).

There is a semi-automatic handloom with jacquard developed in Tamilnadu as shown in Figure 2.43 and 2.44. This loom has improved shedding, take-up, and let-off motion. All primary motions are made manually. It is made of wood material, but the mechanism is made of steel.

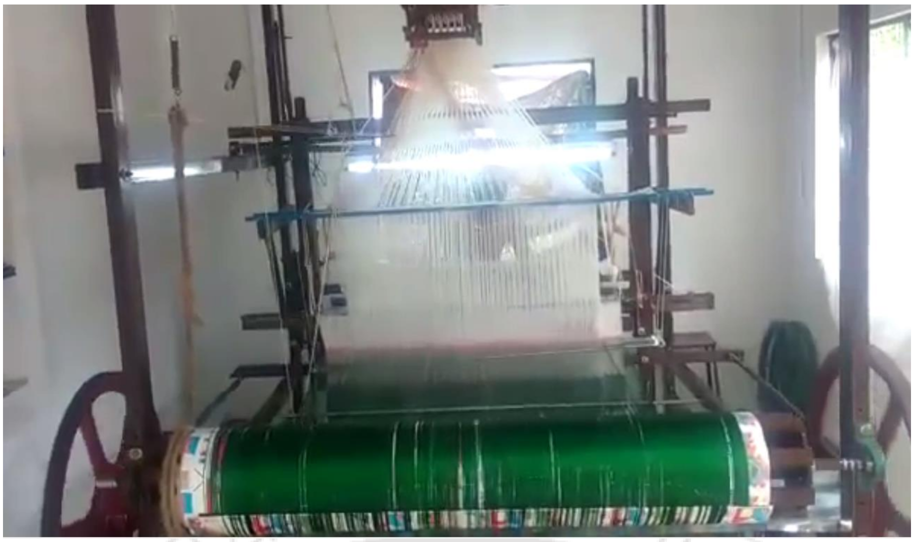


Figure 2.43: Semi-automatic handloom (shedding) is automated, manual picking and beat up) at Tamilnadu [15]

Figure 2.44: Semi-automatic handloom with automated shedding, manual picking, and beat up at Tamilnadu [15]

As shown in Figure 2.45, a semi-automatic handloom for women was ideated and conceptualized in IIT Bombay on 1997, but a physical model has not been made. Existing manual semi-automatic handloom like Nepal-type pedal operated, except for an electric motor, is a power loom in all other aspects and unsuitable for women weavers. Many features were added considering women weavers like lightweight, made out of the tubular structure, and movable parts/systems are enclosed for safety [59].

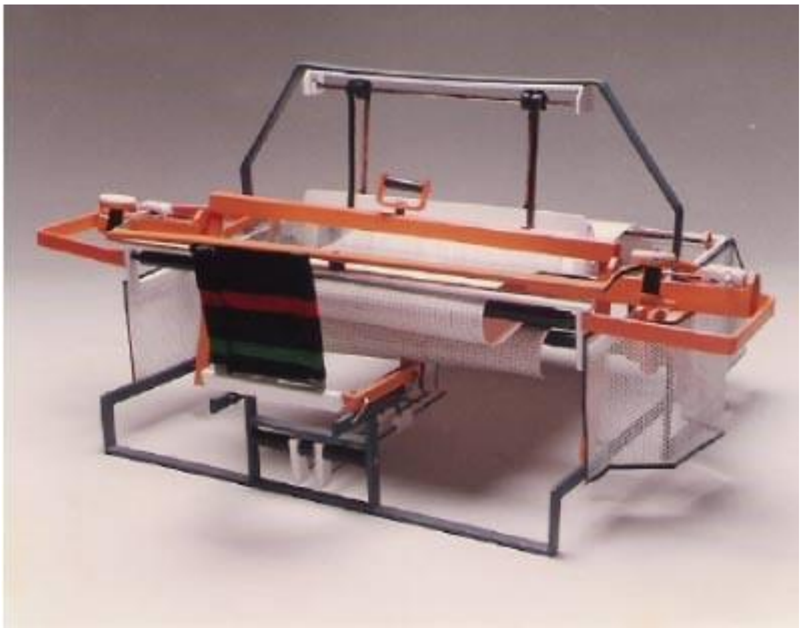


Figure 2.45: Semi-automatic handloom for women

Many old semi-automatic handlooms found in ARTFED, Guwahati, Assam as shown in Figure 2.46.

Figure 2.46: Semi-automatic handloom at ARTFED, Guwahati

"Ahmedabad Textiles Research Association (1990) (ATIRA) has developed LOEPHI (Low Effort Productivity High) Pedal Loom, under the sponsorship of Development Commissioner for Handlooms, Government, of India for achieving higher productivity at the same human effort as in handlooms. An ordinary weaver can operate it with basic ability instead of depending upon the skill and efficiency of the operator. The new pedal loom was evolved through mechanical as well as ergonomic means. Mechanical considerations were made to achieve automatic synchronization of the mechanisms and reduce the energy required to operate the loom for longer duration with the least fatigue. On the other hand, ergonomic considerations were made for better interaction of the man-machine-environment system to improve the system's efficiency, safety, reliability, and productivity at lesser physiological cost and expenditure of other resources. ATIRA LOEPHI Pedal loom needs 35 to 40% less energy than the commercially available pedal loom [35]".

Anon (1991) writes that improved handloom models, designed by the Institute of Handloom Technology (IHT), raise the weaver's productivity and quality of fabrics to international standards. It is estimated that the loom will raise the weaver's income from Rs.24 per day to Rs.44 per day for a work input of eight hours. The improvement is a part of a five-year plan of technical up gradation, covering Karur and Madurai regions. The project limits the up-gradation process to five looms per unit. Proposals for the extension of the project to Andhra Pradesh and Haryana are under consideration.

Kanakarathinam S.M. (1992) writes about handlooms modernization. According to the author, the main factors determining loom productivity include the level of technology of the loom, sophistication of the fabric, number of days worked in a given period, the weaver's ability and skill, and the availability and quality of the raw material, pre-loom conditioning and workplace environment. However, the scope for increasing productivity mainly lies in the up-gradation of loom technology. Roughly during the past four decades, government-sponsored loom modernization schemes have been in force, but progress was found very low. The lukewarm attitude toward implementation, the apathy of the organization concerned with the job of loom up-gradation, and the lack of proper Research and Development Centre's are the reasons for the slow progress. Weavers, too, are reluctant to switch over to new technology partly due to a lack of skill. In order to create a competitive edge over the cost of production, better quality increased wage-earning, and reduce stress and strain, loom modernization is vital. Technological up-gradation is the only way to attract the younger generation to this industry, who often find more gainful employment than handloom weaving [35].

Rangarajan S. (1993) writes in the adoption of ISO-9000 by the handloom sector that some awareness has now crept into the minds of handloom fabric exporters in the country that the key to market access or success depends upon being able to claim that this number ISO - 9000 applies to their business. Handloom exporters should wake up to the fact that failure to comply with the international norms would mean losing their base on the export front. While analyzing various defects in the handloom fabrics, it will be noticed that the defects arise due to the weaver's ignorance of the importance of quality or his eagerness to earn high wages by giving more productivity at the cost of quality. Some of the other defects are due to the antiquated methods and equipment used in pre-loom and loom processes and their limitations in weaving. Systematic training programs are therefore necessary. The weavers and other operators engaged in handloom weaving should be aware of the losses incurred while disposing of such fabrics and the benefits they would get from adopting ISO 9000. In this regard, the government has already taken steps to modernize the existing testing laboratories and establish new laboratories all over India [35].

"India produces 85 percent of handloom products of the world. Other countries having handloom industries are Sri Lanka, Nepal, Bangladesh, Norway, West Indies, Indonesia, Pakistan, Iran, etc." [60]. "There are 3.846 million adult (aged 18 years and above) handloom workers in India. In India, nearly 2.783 million handloom households are engaged in weaving and allied activities. The total weaver household units declined from the first to third handloom census. Fifty-seven percent of the handloom households have a Below Poverty Line (BPL) account. A total of 69 percent of the handloom households undertake commercial production. Nearly 33 percent of the handloom worker households do not have looms. Seventy-six percent of all adult handloom workers are contract workers in states except the North-East region. At the all-India level, the average annual income from all sources, including handloom of 'handloom worker households' in purely commercial production, is 30,747₹ for total handloom households, and the average annual income for handloom households in mixed production is 44,796₹ for total handloom households. The share of handloom income to total household income is 30.2 percent across all handloom households." [1]

It has been emphasized to upgrade the technology to be in the global race of growth and increase employment and Gross domestic product with export earnings. Therefore, it has planned to enhance modernization through various Five-year plans. "In the second five-year plan, priority was set for modernization and re-equipment for cotton textile, jute and sugar industries. In the sixth five-year plan, it has given priority to improving efficiency and productivity through skill development and technological improvements. In the ninth five-year plan, The Technology development board planned to facilitate the development of new technologies and the assimilation of imported technologies. The tenth five-year plan recommended efficiency improving policies for innovation, technology up-gradation, modernization, R & D, skill up-gradation, etc. [16]."

From the literature and product review, it is found that the improved looms were not efficient for commercial use and also sometimes it is not affordable in terms of cost. Therefore, it is seen as a need for further improved loom acceptable to the weavers.

Financial assistance for modernization would be provided by the Handloom Export Promotion Council (HEPC) [35].

For manufacturing tools and methods, Implementation of Design for Assembly and Manufacturing (DFA & DFM) can be beneficial to simplify the loom, reduce assembly and manufacturing costs, improve quality and reduce time to market. A feasibility study was conducted to analyze multiple factors before acting on actual activity to avoid in-process interruption.

2.14 Semi-automatic and automatic convertible handloom

Solar textile looms by Tinytech Rajkot, Gujarat

Figure 2.47: Automatic solar and manual padel convertible loom

“Solar textile looms shown in Figure 2.47 are made for plain weaving with a special interest to cater African market. This loom does not have a jacquard or dobby attachment. These looms operate like automatic through solar power, approximately seven hours per day of weaving. For the remaining time, it can operate with the paddle for shedding motion which operates remaining motions through synchronization. The production rate is 14 meters per hour in automatic looms and 10 meters per hour in the semi-automatic loom. 150 meters of cloth per loom can be produced daily if it operates 7 hours automatically and 5 hours semi-automatically. 200 days per year have been considered for working days. 12-meter cloth per year per person is required for a decent living. So, 1200000 meters cloth required for 100000 people in a year, which can be produced through 40 looms” [61].

SunKargha semi-automatic handloom by Reshamsutra, New Delhi

Figure 2.48: Paddle-operated semi-automatic handloom

Only paddle to be operated manually; remaining operation is done automatically in the loom shown in Figure 2.48. Picking is done in a new way by pulling and pushing the picker through a string mounted on top, which moves up and down. Sley oscillating movement helps to reduce the tension of the top string connected between the picker and effort side of the 1st class lever. This loom can also do regular weaving, not ornamentation. The load side of the 1st class lever passes through warp yarns, which may damage the warp yarn in this loom [62].

2.15 Semi-automatic handloom converted from traditional handloom

A Fully automatic loom is made by upgrading the wooden handloom by Jubarani Ningombam. This loom is not flexible for developing a tailor-made ornamentation design. It is made of wood material, but the mechanism is developed of steel; therefore, it may be non-durable. Maina Automatic handloom has attempted to make semi / fully automatic loom upgraded from handloom. Inventor automation, Coimbatore also developed a sheet metal automatic handloom pneumatically operated, as shown in Figure 2.49. This loom has an overhang sley; therefore, the sheet thickness of the metal sheet used to build the frame is more than our sheet thickness. Buta sequences, automatic take up and let off motions, auto-adjusting tension control systems. This handloom looks like welded sheet metal in many places [18].

Figure 2.49: Automatic sheet metal pneumatic handloom

2.16 Take up gear mechanism

There are various types of existing take-up mechanism shown in Figure 2.50 to 2.52.

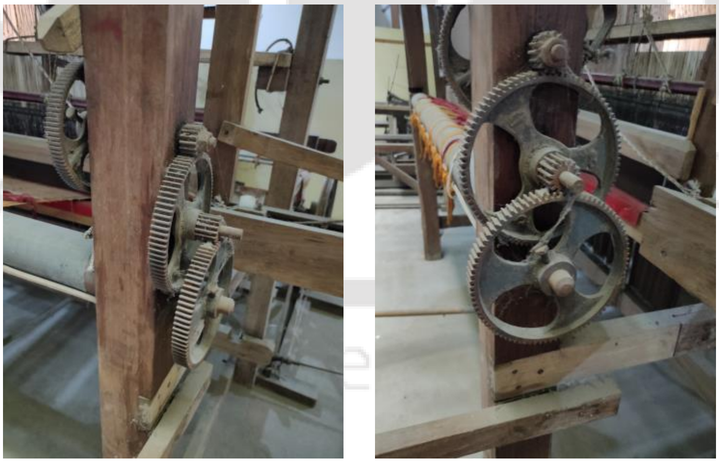


Figure 2.50: Gear mechanism in semi-automatic handloom at Handloom development & research center, Ambari, Guwahati

Figure 2.51: Gear mechanism in semi-automatic handloom at ARTFED, Guwahati

Figure 2.52: Actuator in take-up gear mechanism in semi-automatic handloom at ARTFED, Guwahati

2.17 Jacquard

Joseph Marie Jacquard invented the jacquard mechanism in 1804 to weave patterned fabric. Earlier complex patterns must be set up in advance and also need an assistant during weaving. After the invention of the jacquard, a single person could weave patterned fabric. Generally, jacquards are made up of wooden frames with metallic mechanisms. It needs two types of material and two different types of skilled people to build the same. Wood wears out early, and fasteners loosen out during fastening with metal is an additional problem.

Two types of traditional wooden and hybrid material type are commonly used models are shown in Figure 2.53 and 2.54.

Figure 2.53 Wooden Jacquard model with less metal

Figure 2.54: Existing jacquard with wood structure and metallic mechanism parts

Another jacquard shown in Figure 2.55 found in Handloom development and research centre, Ambari, Guwahati

Figure 2.55: Jacquard at Handloom development and research centre, Ambari, Guwahati

2.18 Handloom data

The number of loom in weaver households by type is shown in Table 2.22.

Table 2.22: Number of loom in weaver households by type

Type of looms	**Total Looms**	**No. of looms in weaver household**
Pit loom with Dobby / Jacquard; Other Pit looms	0.815 million 0.396 million	1.141 million (42.2%)
Frame loom with Dobby / Jacquard; Other Frame looms	0.291 million 0.601 million	0.852 million (31.5%)
Loin looms	0.405 million	0.405 million (15%)
Other looms (Inchakaranji looms, Chittaranjan looms, Malabar looms, Manipuri looms, Rajasthani looms, Kashmiri looms, etc.)	0.316 million	0.316 million (11.3%)
Total	2.824 million	2701080

67.3% of pit looms and 32.6% of frame looms are with dobby/jacquard, which show a necessity to design a handloom for ornamentation as very low number of existing dobby/jacquard handloom, also causes low income. 17.6% of handlooms are idle in the weaver's household unit, followed by 5.3% of idle handlooms with the master weaver.

The distribution of non-households by type of looms is as below Table 2.23.

Table 2.23: Distribution of Non-households by type of looms

	Pit looms		**Frame looms**		**Loin looms**	**Others**	**Total**
State	**Pit loom with Dobby / Jacquard**	**Other Pit looms**	**Frame loom with Dobby / Jacquard**	**Other Frame looms**			
Andhra Pradesh	645	441	53	93	0	117	1349
Arunachal Pradesh	2	0	0	0	2	0	4
Assam	1467	88	34	179	39	386	2193
Bihar	52	2	2	12	0	1	69
Chhattisgarh	0	61	0	216	0	102	379
Delhi	0	25	6	1380	0	6	1417
Goa	0	0	0	15	0	0	15
Gujarat	7	2	106	14	0	3	132
Haryana	462	2329	221	7261	0	805	11078
Himachal Pradesh	0	506	64	359	0	0	929
Jammu & Kashmir	2	16	1	5	0	15	39
Jharkhand	282	428	215	639	0	67	1631
Karnataka	330	35	174	887	0	396	1822
Kerala	53	8232	31	11345	0	1230	20891
Madhya Pradesh	109	642	79	921	0	155	1906
Maharashtra	702	32	11	184	0	71	1000
Manipur	61	13	60	97	501	63	795
Meghalaya	0	0	0	0	0	0	0
Mizoram	371	85	355	113	56	34	1014

Nagaland	113	7	52	45	499	10	726
Odissa	3	2	172	359	0	0	536
Puducherry	802	0	0	23	0	0	825
Punjab	25	20	13	56	0	0	114
Rajasthan	115	611	7	203	0	161	997
Sikkim	0	0	0	0	2	0	2
Tamil Nadu	9505	6257	7	5003	0	7260	28032
Telangana	613	1531	268	3029	0	110	5031
Tripura	16	47	0	225	16	33	337
Uttar Pradesh	8653	20279	849	2512	0	217	32510
Uttarakhand	1	42	4	982	0	75	1104
West Bengal	3394	243	346	436	3	483	4905
All India	27785	41976	3130	36593	1118	11700	122302

Pit looms with throw shuttle are used to make the finest varieties of fabrics with various designs and textures like brocades, jamdanis, Patola, and Himroos. Frame looms can use more than two treadles and weave fabric in mass. A loin loom is a portable loom without any solid frame suitable for weaving various designs and textures. These looms are not suitable for mass production.

Independent weavers primarily own Pit looms (42.2%), followed by Frame looms (31.5%). Non-households also have more pit looms (57%) than frame looms (32.5%).

Master weavers prefer frame looms (55%) over other looms.

It has been observed that fly shuttle pit looms are less productive than frame looms or semi-automatic handlooms [37].

India has the most significant number of looms in place to weave fabrics, accounting for 64 percent of the world's installed looms. However, 98% of the looms are accounted for by India’s power loom and handloom sectors, which use mostly outdated equipment and produce mostly low-valued unfinished fabrics. Composite mills account for 2% of India’s installed looms and 4% of India’s fabric output.

2.19 Productivity in traditional handloom

Traditional handloom can produce 1617 million yards per year considering 200 working days and 9 hours of work per day with 2 million handlooms (64% Throw shuttle, 35% Fly shuttle, 1% others) based on the data in 1945. Fly shuttle looms are 75% more productive than Throw shuttle looms.

The average production per handloom per day is found to be 5.12 meters in India. In urban households, it is 8.51 meters and 4.47 meters in rural households; the lowest productivity is 0.63 meters found in Assam [63].

The emphasis on productivity and quality has dramatically developed the weaving technology, and as a result, the working hours required to weave fabric from a loom have been reduced from about 20 hours to 0.25 hour per unit production during the last 125 years. In the last 50 years, there has been a reduction of 95% in operative hours per standard unit produced.

2.20 Work-related musculoskeletal disorders of the weaver

"All handloom activities have certain risk factors, i.e., awkward postures, forces, repetitive movements with inadequate rest. It directly declines the productivity and quality of work. In weaving, shoulders are involved in repetitive movements without breaks for throwing shuttle and moving sley. This repetitive movement of the hand increases the risk of neck, upper arm, and shoulder musculoskeletal problems, as they are operating heavy sley continuously without taking adequate breaks for rest. The following Table 1.1 shows occupational health problems due to weaving." [64]

Previous research with workers from the carpet weaving industry of Iran also shows a high prevalence of musculoskeletal problems due to working postures, poor tool (loom) design, long hours, repetitive work, and seat type [65].

Correctly diagnosing work-related musculoskeletal disorders (WMSDs) problems would pave the way for proper design solutions regarding tools, workstations, and work process design [43]. "Overall efficiency in handloom weaving is reported to be 30 percent; out of this, the loss in loom efficiency due to warp breaks, shuttle changes, etc., account for 15 percent to 20 percent" [66].

2.21 Historical advancement of weaving technology

Except for a few activities elsewhere, the significant developments in textile took place in England. The major shift from agriculture to the woollen industry in England came in the 14th century. The cloth was produced on hand-looms that were not equipped with fly-shuttle in all these years and a few hundred years later.

In 1733, John Kay invented the fly shuttle, which enabled wefts to be inserted more rapidly. Edmund Cart Wright, an English clergyman, invented a power loom which could be operated from a single point by two strong men. Fortunately, steam power was available by 1765.

Soon power looms were driven by steam, and most of the wooden parts were replaced with iron. These looms then were stopped every few minutes to replace the empty weft pirns or cop in the shuttle, and this limited the number of looms; a weaver could operate to about four. James Northrop, an English man, invented an automatic weft transfer system that replaced the shuttle's weft pirn without slowing or stopping the loom in 1889.

Similar developments took place elsewhere. Ruti, a major loom maker in Switzerland, manufactured an automatic bobbin changing Northrop loom in 1898. After World War II, more productivity and efficiency were essential to overcome increasing labor costs in Western countries. Limitations of Shuttle Looms Despite the relatively high speed, and efficiencies in a loom with conventional picking, the productivity of these machines will continue to be limited as long as their fundamental constructions involve the use of shuttle propulsion. It is known that the power required for picking is proportional to the cube of the loom speed. If the loom speed is increased from 200 to 300 picks per minute, the power requirement will increase by a factor of (3/2) 3, i.e., 3.4 times approximately[15]

2.22 Disadvantages of Fly-shuttle handlooms

- The tremendous strain is imposed on the picking mechanism, thus rendering it liable to frequent failure.
- The tremendous amount of noise and vibration
- Because of superior energy in the shuttle, greater strain is again imposed on the checking mechanism.
- The movement of the shuttle will be more challenging to control, and there will be a greater possibility of its ejection from the loom.

The dynamic problems created by the picking and checking mechanism and the inherent process of pirn winding for shuttle looms encouraged the loom makers to develop alternative means of weft insertion in which the heavy shuttle is not projected forwards and backward across the width of the loom. It is customary to refer to these looms as shuttleless looms.

2.23 Handloom development efforts in India

Many government organizations are working to support the handloom sector as below.

The All India Handloom Board

The All India Handloom Board was initially constituted in 1945 by the Department of Industries and Civil Supplies to assist the Government of India in policy-making for the sector. This board's three essential functions are research, supply of raw materials, and marketing. This board was dissolved in 1947. The All India Handloom Board formed in 1952 again along with 88 non-institutional members, comprising weavers and artisans across India. This board assists in proposing schemes for developing this sector to the Government of India. Only six meetings in 15 years made it insignificant for the sector's development; therefore, this board was dissolved on 27 July 2020. Now, the Government of India seeks direct feedback from the weavers and artisans from a standard website where all scheme details will be available.

Khadi and Other Industries Development Act 1953: This act is passed to raise funds for the sector and organize weavers in cooperatives.

All India Handloom Fabrics Marketing Cooperatives Society: This apex body has helped facilitate handloom fabrics marketing since 1955.

Weavers Service Centre (WSC) and the Indian Institute of Handloom Technology (IIHT): Weaver service center provide infrastructure support in applied research for technological intervention, service, and training. IIHT work on the supply of input material like yarn, dye etc.

Handloom and Handicrafts Export Corporation of India Ltd (HHEC): HHEC was established in 1958 to promote the export of handlooms.

Office of Development of Commissioner for Handlooms: It is established in 1976 to ensure the scientific growth of the handloom sector by a high-powered team. They implement various development and welfare schemes to promote the production and marketing of high-quality and high-value handloom products for the benefit of handloom weavers.

National Handloom Development Corporation (NHDC): It was established in 1983 to ensure a steady supply of raw materials like yarn, dyes, and chemicals in the handloom sector.

Textile Research Associations

There are eight Textile Research Associations engaged in the work of research and development in this sector: -

1. Ahmedabad Textile Industry’s Research Association (ATIRA)

2. Bombay Textile Research Association (BTRA)

3. South India Textile Research Association (SITRA)

4. Northern India Textile Research Association (NITRA)

5. Man-Made Textiles Research Association (MANTRA)

6. Synthetic and Art Silk Mills Research Association (SASMIRA)

7. Indian Jute Industries Research Association (IJIRA)

8. Wool Research Association (WRA)

[48]

Behind the failure to protect the handloom's identity [67]

A cursory look at the various legislations made to protect handlooms shows the shifting importance given to the industry by the state. In 1950, when India emerged as a republic, the central government declared the production of several handloom products the prerogative of the handloom sector. Traditional products like border saris, dhotis, and bedsheets were reserved exclusively for handlooms. The reservation order combined the unique character of handloom production with its labour-intensive nature and sought to preserve handloom identity while becoming a cloth of the masses. Unfortunately, inefficient implementation of the order slowly led to the mushrooming of power looms in the decentralized sector, which produced perfect imitations of handlooms.

Meanwhile, the state maintained a conscientious attitude by forming several appointed committees to look into the issues affecting the handloom sector. The Ashok Mehta Committee appointed by the central government in 1964 suggested that the production of saris should remain the exclusive prerogative of the handloom sector. A decade later, the high-powered Sivaraman Committee (1974), in its report, pointed out that every new power loom made six handlooms redundant and led to large-scale unemployment in the rural areas. It clearly stated that the manufacture of handloom goods is a cottage industry, as one person cannot carry out the entire production process. The committee opined that as a rural industry, the handloom sector provides a livelihood to a considerable number of the rural population. The verdicts of these various committees strengthened the argument for special legislation to protect handlooms. Finally, the Handloom Reservation Act came into existence in 1985.

It may seem peculiar that the significant narrative of the policy framework revolves around reservations for certain handloom varieties either as a means to protect distinctive identities or to prevent machine-made imitations. The purpose of the reservation is to provide an appropriate place for the handloom or measure of increasing growth in the sector. It should be seen in the backdrop of the phenomenal increase in power looms in the strongholds of handloom and the direct impact on the survival of the handloom sector. From the beginning of policy making in independent India, the two industries were positioned competitively. However, the interesting fact is that power looms grew under the protection offered to handlooms. Many factors contributed to this growth. For instance, until 1955, the power loom was clubbed with handloom under the same excise Act and was eligible for duty exemption under this Act. According to the Act, an exemption was given to units with less than five looms. Power loom units took advantage of this clause and dispersed their units to evade duty. There was a stipulation for power loom units to register, but the regulation of power looms was largely ineffective. Specific provisions for handloom were always availed by the power loom sector too. For example, under the Hank Yarn Obligation Act, it is mandated that 60% (now reduced to 40%) of all spinning mill production should be in the form of hank yarn, which is the form in which handloom needs the yarn. After lobbying from mills, the power loom industry used the government subsidy for hank yarn. This kind of contravention was possible as power loom owners had formed strong alliances with the state and local political interests.

By 1974, when the exemption to power loom units with less than five looms was revoked, the growth of power looms, and their domination over handlooms was complete. By the early 1980s, power looms were supplying one-third of the total textile requirements in the country. From the 1985 textile policy, it is clear that emphasis shifted from expanding the potential for employment in rural areas to increasing productivity through modernizing technology.

Changing policy discourse [67]

If numbers could tell a story, the reduction in the number of handloom weavers over decades makes a significant point. Official surveys published by the Office of the Development Commissioner (Handlooms) suggest the number of weaver families reduced from 12.4 million in the 1970s to 6.4 million in 1995, and further down to 4.4 million in 2010. Now, only 3144839 households are involved in this sector as per Handloom census 2019. The failure of the various methods adopted to protect the handloom sector is clear from this sharp decline in numbers. Why did the Reservation Act not prevent growth in imitations from power looms? Why did the 'handloom mark' (constituted in 2000) fail to establish the distinction between the power loom and handlooms? Why did the state allow power loom interests to govern the interests of the handloom department? For instance, in all the annual exhibitions for promoting exports in the Handloom Promotion Council, very few handloom organizations are represented compared to power looms. In the annual state-sponsored exhibitions promoted with much fanfare, more than 50% of the stalls exclusively exhibit power loom products. Two significant causes can be highlighted. One is the evident lack of political will on the part of the government and a growing indifference to the objective of protecting rural livelihoods. The other is a growing belief that the market is the space where competencies will be tested, and the best will eventually win.

However, it is a fact that the markets could not catalyse growth to generate adequate employment opportunities and provide alternatives to those who lost their traditional livelihoods. It is clear from the continuous migration of people across the country from the rural areas to the few urban spaces available. The employment creation in the non-farm sector has decreased though the unemployment rate has been stable over the past few years to 5-6%. If we observe the data for employment generation, which is available from 2009, the projection for 2016-17 looks very bleak. As the president recently stated, there is a need to generate 115 million non-farm jobs over the next decade to employ the emerging workforce in the country gainfully. However, these daunting statistics have not managed to shake the state's belief in the power of the market. The acute agrarian distress and growing migration of farmers, not to forget the increasing suicides of farmers across the country, has not shaken the belief in the market as the provider of solutions. This conviction has added strength to the state policy of withdrawing from many public sectors and increasing the share of private players. In this situation, factors like increasing growth in employment and lending a hand to sectors supporting existing livelihoods no longer form a part of the state policy discourse.

The 1985 textile policy can be seen as a watershed of sorts. It heralded revolutionary changes in attitudes towards the unorganized sector, cottage industries, and industries based on traditional technologies. The proclaimed objective became one of increasing textile production, and employment generation became an argument that merely supports this primary objective. This policy changed the classification of weavers from cooperative or independent to a weaver who weaves coarse cloth earning low wages or a weaver weaving fine cloth earning higher wages. Based on this division, the weaver weaving coarse cloth was recommended to shift either to the power loom or out of the weaving profession. The market play is evident in this policy formulation, which assumes that a weaver with better wages will survive while others would have to migrate. With a clear emphasis on increasing productivity, this policy sought deregulation of textile mills.

In a way, the 1985 policy forms the foundation for all the subsequent articulations on this sector to date. From then on, efficiency, productivity, and healthy competition between the three sectors (mill, handloom, and power loom) became the parameters for assessing the fitness of the sector.

2.24 Government schemes for renovation/up-gradation of handlooms.

The Government of India does major interventions as below

i) Skill up-gradation on new weaving techniques, new technology, new design, development of eco-friendly dyes, new dying techniques, e-commerce, and organizational management

ii) Infusion of new and contemporary designs through block-level professional designers linked with marketing agents.

iii) Product diversification

iv) Technology up-gradation

v) Improved access to subsidized raw materials along with a 10% subsidy on cotton, domestic silk, woolen, and linen yarn

vi) Access to low-interest credit with 6% annual interest up to 10000 ₹

vii) Common infrastructure development for organized work through Block Level Cluster and 100% financial assistance up to 0.12₹ million to make individual work shed

viii) Central professional query resolution through Bunkar Mitra Helpline number, i.e., 1800 208 9988

ix) Welfare schemes for weavers, i.e., Pradhan Mantri Jeevan Jyoti Bima Yojna (PMJJBY) for age group 18-50 years by paying 330₹ annual premium for 0.2₹ million life cover, Pradhan Mantri Suraksha Bima Yojna (PMSBY) for age group 18-70 years by paying 12₹ per annual premium for 0.2₹ millions of risk coverage for accidental death or total disability and 0.1₹ million risk coverage for partial disability and Mahatma Gandhi Bunkar Bima Yojna (MGBBY) by paying only

80₹ as enrolment fee, rest premium borne by Government of India for weavers of age 51-59 years along with the additional benefit of Siksha Sahyog Yojana

x) Brand building through handloom mark on handloom products under India Handloom Brand

xi) Marketing assistance by Handloom expos, District level events, and Craft Melas in the country, including promotion of e-commerce platform (23 e-commerce companies already connected) and linking handloom with high-end fashion like BIBA, Peter England, and ONAYA already launched handloom products

State Government also played a significant role in the development of Handloom sectors.

The following Table 2.24 shows the major program run by the Government of India and the State Government of Assam

Table 2.24: Handloom program run by Government of India and State Government of Assam

Handloom program run by Government of India	**Handloom program run by State Government of Assam**
National Handloom Development Programme (NHDP)	Handloom Training Centre (HTC)
Comprehensive Handloom Cluster Development Scheme (CHCDS)	Handloom Training Institute (HTI)
Hatkargha Sambardhan Sahayata (HSS)	Weavers Extension Service Unit (WESU)
North Eastern Region Textile Promotion Scheme (NERTPS)	Research and Development
Handloom Weavers Comprehensive Welfare Scheme	Handloom Production Centre (HPC)
10% subsidy in Hank Yarn Scheme	Economic Upliftment of Handloom Weavers
	Publicity and Exhibition

Among these schemes, Hatkargha Sambardhan Sahayata (HSS) central scheme aims to improve productivity by using improved handloom with Dobby / Jacquard along with improved fabric quality. The central government bears 90% cost of the loom, and the state government takes full responsibility for implementation.

Awareness of these schemes is very poor in the handloom households. Major 13 schemes are checked for household awareness during the Handloom census 2019-20. The following Table 2.25 shows the households in percentage aware of these schemes.

There are 115 registered users of the GI certification for Benarasi handloom without any cases filed on infringement of intellectual property. Still, the Uttar Pradesh government is trying to connect handloom weavers in Varanasi with designers to help them create intellectual property. Uttar Pradesh government is trying to create linkages with private partners for handloom and khadi and tying up with premier institutions such as NIFT and IIT-Kanpur for design development and product diversification[15].

Table 2.25: Awareness of relevant schemes in households (2545312)

Name of the Scheme	Handloom Households (in %)
Weaver's Health Insurance Scheme	3%
Margin Money for Working Capital	7.6%
Marketing incentive / Rebate schemes	9%
Skill up-gradation (training, workshop)	9%
Participation in fairs / Haats / Exhibitions	9.4%
Credit Waiver (Loan)	10.5%
Yarn Supply through National Handloom Development Corporation	10.8%
Mahatma Gandhi Bunkar Bima Yojana	12%
Loom and Parts / Workshed / Accessories	14.5%
Common Facility Centre / Calendaring Machine	22.4%
Handloom mark	22.4%
Design training	25.5%
Housing Scheme	33.1%

2.25 Handloom Awards

National awards are as below

Sant Kabir Award – for weavers who made some innovative product

National award (Kamaladevi Chattopadhyay & National Merit Certificate) for Handloom weavers

National award (Design development)

National award (Marketing of Handloom products)

West Bengal, Tamil Nadu, Telangana, Andhra Pradesh, and Chhattisgarh are a few states with schemes to award weavers.

Following challenges with the percentage of agreed handloom weavers in Orissa were observed on a survey of 201 participants.

Shortage of raw material, ineffective co-operative government machinery, and infrastructure bottleneck challenges are faced by more than 90% of weavers in Orissa, as shown in Table 2.26. It is also found that hank yarn is sold at a high price to individual weavers than to master weavers to stop entrepreneurship skills or self-employment in Orissa. Weavers could

Table 2.26: Selected challenges faced by handloom weavers with % of agreed handloom weavers[32]

Challenges faced by weavers	% of agreed weavers
Ineffective co-operative system and ineffective government machinery	91%
Exploitation by the master weaver and the middle man	33%
Shortage of raw material	100%
Lack of working capital	71%
Infrastructure bottleneck	90%
Lack of product diversification	6%
Competition from the power loom sector	42%

not weave with ornamentation as designed fabric due to proper infrastructure. Warping is challenging in the traditional method in the rainy season and requires ample open space [32]. It is also found that weavers who have adopted power looms did not achieve the desired result due to a lack of electricity and infrastructure for pre and post-weaving activities. 89% of weavers feel that the handloom can survive with its unique design capability over the power loom[32].

Seating system

A literature review is done considering the 'adjustable chair design' keyword through a keyword search strategy. 561 articles were found, but only 37 were found relevant to this topic for review. Research on seating systems has considered the following design variables, as shown in Table 2.27.

Table 2.27: Selected seat components in bold and design variables for the seat for a weaver of handloom

Seat component	**Design variable in the seat**
Seat pan	Height, width, length, angle, contour
Lumbar support	Height, Depth, Contour
Foot rest	Height, angle

Table 2.28: Indian anthropometric data of selected design variables for the seat of a handloom weaver

Anthropometric variable	**Male**		**Female**	
	95 percentile	**5 percentile**	**95 percentile**	**5 percentile**
Sitting height	893	757	809	698
Eye height, sitting	805	678	731	574
Acromion height, sitting	608	484	558	462
Elbow height, sitting	220	158	265	124
Knee height, sitting	567	497	520	462
Popliteal height, sitting	471	380	441	365
Hip breadth, sitting	405	272	429	259
Buttock to knee length, sitting	615	489	585	459
Buttock to popliteal length, sitting	512	399	494	384
Maximum body breadth	482	379	449	319
Abdominal depth	327	227	270	201
Omphalion height, (sitting)	221	154	260	165

Anthropometric body dimensions of India were selected based on the design variables of required seat components for the weaver of handloom in Table 2.28.

The anthropometric variable of seat design is shown below in Figure 2.56 showing each variable.

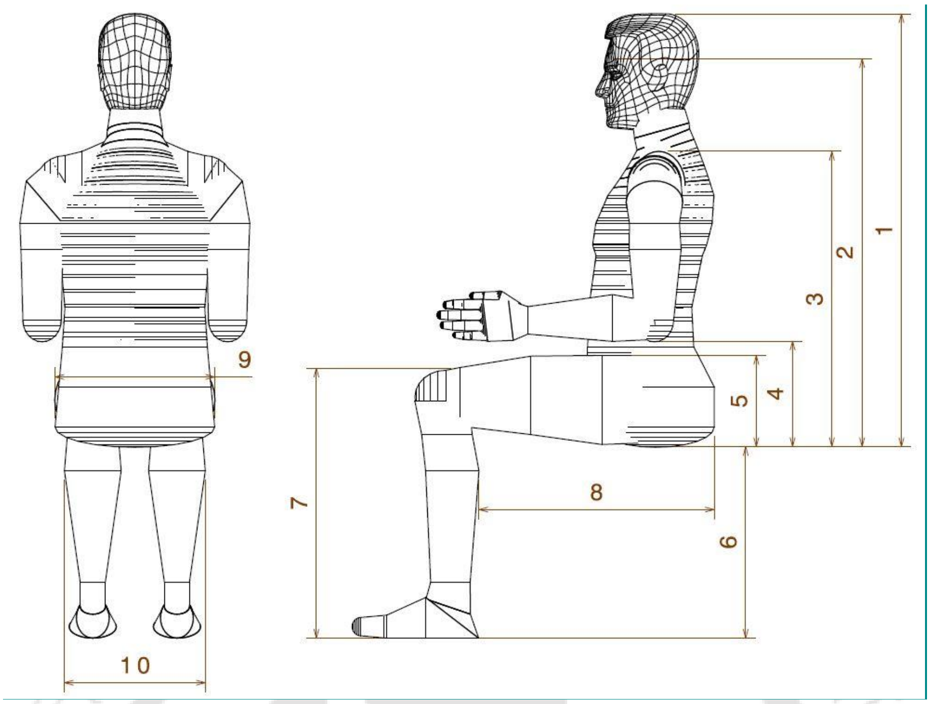


Figure 2.56. Anthropometric measures for seat design

In Figure 2.56, all the representation belongs to each number is given below in Table 2.29.

Table 2.29: Dimensional representation of Figure 2.56

1	Sitting height
2	Eye height
3	Shoulder height
4	Elbow rest height
5	Thigh clearance
6	Popliteal height (Stool height)
7	Knee height
8	Buttock – Popliteal length
9	Hip breadth
10	Knee to Knee breadth

A subjective framework for seat comfort based on a heuristic multi-criteria decision-making technique and anthropometry was developed for automobile seat comfort based on feedback by users [68]. Automobile seating is designed for sitting, putting brake, operating the accelerator, and handling steering by the driver. The driver uses hand and leg both during driving, but it is not in a regular dynamic pattern like a weaver does in a handloom. Seat-back angle, seat-bottom angle and foam density, height above the floor, and pressure of armrests are the affecting factor in seating posture. Seat length and width should be between 35cm to 40cm. The seat height should be less than the distance from knee to feet. A seat bottom posterior backward inclination of 5 degrees is preferable but should not exceed 0-10 degrees. 135 degrees of thigh trunk angle is a neutral position for tension in the thigh muscles. The optimum seat-back inclination is 110 degrees in a normal sitting posture [69]. The backrest should have an adjustment in both vertical and horizontal planes for proper lumbar support [70]. Seat-back inclination range of 110 - 120 degrees is better when the seat is subjected to vibration, especially for operators who work for a long time. Also, these effects can be minimized by attenuating seat and seat material [71]. Range of seat-back angle 95 – 120 degrees found in bus and airplane, but a train seat was found till 145 degrees. Seat pan angles are 11-16 degrees in buses, 5 to 7 degrees in an airplane, and 10 degrees on the train [72]. The adjustable height range of the seat pan should be 40cm to 47cm from the floor based on Indian anthropometric data [73].

Although the chair has the adjustment facility, weavers lack adjustment knowledge and the importance of doing it [74]. The direction of hand movement significantly affects shoulder strength when working at or above shoulder level. The optimum position that maximizes shoulder strength is vertically downwards [75]. The optimum and preferred hip joint angle is 79-130 degrees, knee joint range is 84-147 degrees. Similarly, optimum and preferred elbow, ankle, and shoulder joint ranges are 80-167 degrees, 77-130 degrees, and 0-63 degrees, respectively. The optimum or preferred neck flexion angle is 33-66 degrees, and the wrist range is 133-206 degrees [76]. Also, it should be noted that the pedal position far under the workstation is preferred for leg comfort [77]. One researcher checked differences in pressure sensitivity of the body area in contact with the seat and found that the area of the seat touching the shoulder is more sensitive than lower down the back and the area between the shoulders [78]. The differing sensitivity in the buttock and thigh areas are essential factors along with anthropometry data of the regional body dimensions during seat design. Height adjustment is a crucial design variable in the prolonged use of a seat [79]. The concave surface under ischial tuberosities in the seat pan area with the downward angle in the front of 18 cm and a maximum 8-degree forward inclination angle has improved seating comfort than the plain seat pain area [80]. Previous studies indicated that flat or rearward sloping seats promote lumbar kyphosis, while forward sloping seats preserve the lumbar lordosis; therefore, forward sloping seats are popular among researchers to study [81].

Pre weaving activity plays a critical role in weaving as the output of pre weaving is input for weaving. The warping drum and creel is to be designed in sheet metal to synchronize between pre-weaving and post weaving activities properly. Earlier, this process was very tedious. Warp yarns were lying on the ground, requiring much space to do this activity. Therefore, yarn wind directly from the hank to the warp beam.

Primary finding of literature is all about necessity of pre-weaving, improvement of handloom productivity, lower energy requirement, material suitable for implementing automation, design for manufacturing, assembly and dis assembly, controlling picks per minute by adjusting take-up motion

Chapter 3: Research Methodology

3.1 Research Methodology

The experimental and descriptive approach under the qualitative design methodology was followed to identify the problem in handloom and to overcome these problems; creative design methods were used, such as brainstorming after thorough literature and product review.

3.2 Design Methodology

The design methodology adopted is two-pronged

1. Holistic Approach
2. Piecemeal Approach

Holistic Approach

The handloom as a whole is considered for functional requirements in the holistic approach. In this case, the constraint was using available structural members like L-member, square rectangular, and round cross-sectional tubular structural members. Another constraint was to explore the structure keeping in mind easy disassembling, packing, transportation and reassembly. Based on these, several concepts were developed.

Piecemeal Approach

In the Piece meal approach, all different sub-systems of the loom are explored separately by studying the existing mechanisms from looms irrespective of handloom or power loom. Then different systems of that sub-system are compared, and only those compatible with the semi-automatic handloom are adopted with the required design input.

Human Factors Involved

The need to design a semi-automatic handloom has become very strong because of Human Factors involved with the present types of looms available. These looms evolved in two ways.

i. From existing handlooms
ii. Imitated from power looms

In either case, the process was an adaptation, and various problems remained directly related to the human factors involved.

In the first case, various mechanisms like take up, let off etc., are added to the existing looms designed for more force requirements. Also, mere mechanisms did not solve various problems associated with these looms.

In the second case, the looms have been adopted from power loom, e.g., Hattersley pedal loom, Madanpura pedal loom, Nepal pedal loom, and numerous such looms. Since these looms were directly imitated/adopted, functionalism is stressed, and human factors were neglected. One point to consider in this respect is the absence of seating arrangement for the weaver in these looms. Now there are other factors involved, and these are

i. Postural issues and strength required to operate these looms
ii. Noise
iii. Vibration
iv. Visibility to check the quality of materials woven
v. Dust

These factors were studied in detail for the existing looms, and various possible alternatives were evaluated. The same was included in the design

3.3 Preliminary findings from literature and product review

The data collection and literature study of existing semi-automatic handlooms lead to certain conclusions.

i. The manual picking mechanism reduces the loom's efficiency and needs much more attention from the weaver.
ii. The picking mechanism also greatly influences the loom design and postural issues.
iii. Complicated mechanisms scare off the weavers when they try to weave on semi-automatic looms. Also, these mechanisms are responsible for the poor quality of materials and low productivity of the weavers on these looms.
iv. Once the loom's motions are automated, these needs higher energy to operate due to introduced linkages, so weavers are easily fatigued.
v. Automatic take-up motions are the bone of contention as these were found to be very cumbersome and adjusted by the weavers.
vi. Wherever take-up mechanisms were introduced without controlled beat-up, results were disastrous.
vii. Existing semi-automatic looms were very complicated to assemble, and when purchased, unless assembled by the manufacturer, weavers could not assemble them themselves.

viii. Despite various shortcomings, existing semi-automatic looms were costing higher and more complicated to manufacture due to lack of appropriate design inputs.

These, compounded with other desirable factors, provide specific criteria on which to base the design (These were not separated from design concepts at this stage).

A Design Brief is prepared based on all the above.

3.4 Design Brief

1. Structural aspects

a. It should be a frame loom and sturdy enough to withstand rigorous use.
b. The height of the loom should be such that the weaver, when operating the loom, gets an unobstructed view of his/her surroundings to provide for inter-group communication with other weavers working on other looms.
c. The product may have a machine look but should not have a structure that conveys a feeling of heaviness.
d. Should possibly use existing angular/tubular structural members for easy availability and manufacturability. Minimum parts should be used to construct the loom.
e. It should be easily disassembled and reassembled, and the members should provide compact packing for transportation.
f. The structure should not require expensive machinery for its manufacture with a cost-effective manufacturing process.
g. It must provide easy ingress and egress by the weaver to the loom seat.
h. Appropriate seating arrangement integrated into the structure

2. Operational aspects

a. It should accommodate a longer length of the warp.
b. The loom's width should accommodate most of the everyday items of daily use.
c. Manual shedding for easy changeability of design is to be incorporated and provide simple structural design.
d. The shuttle needs to be propelled automatically.
e. Should need minimum effort to operate the loom.
f. Automatic take-up motion with easy adjustability for pick spacing should be incorporated. It also provides for take-up disengagement when the loom is mended for broken ends.

g. Tension-activated oscillating back rest is required.
h. Automatic temple motion needs to be incorporated.
i. Existing reed, healds, shuttle, and pirns should be possible to be used

3. Appurtenances

a. The possibility of including auxiliary equipment/attachments like multiple shuttle boxes, dobby, and draw boy should be explored.

4. Marketing aspects

a. It should be a high-productivity commercial loom to generate gainful income for the weaver.
b. It should be workable with existing preparatory machines like warping drums etc.
c. It should be targeted at centralized handloom production centers and marketable to an individual weaver.

5. Human factors

a. It should provide continuous comfortable weaving for hours and reduce fatigue compared to other looms.
b. Operations should follow and reinforce inherent human capability.
c. The visual aesthetic of the loom should inspire working on the loom.
d. All grips are to be designed to take into account human limitations.

Based on the feedback received from weavers on the design brief, specific criteria were segregated and noted.

1. Simplicity of mechanism, operation, and form.
2. Easy knockdown and reassembly.
3. Incorporation of mechanical shuttle propulsion.
4. Controlled beating of the weft.
5. Auto sequencing system for healds.
6. Easy manufacturability and low cost with standardized interchangeable components.
7. Possibility to vary loom size and capacity.
8. Light weight.
9. Multiple shuttle box.
10. Provision for dobby/jacquard attachment.
11. Possibly weave diverse fibers and materials like jute fiber to gunny bags, silks, and bandage materials for medical application.

12. Easily adjustable take-up motion in conjunction with let-off motion synchronized with beat up motion.

An interacting matrix was plotted to find the order of precedence.

3.5 Interaction matrix

In the interaction matrix, a cross in a box denotes that the row concerned has greater importance than the column concerned.

Table 3.1: Interaction matrix

		Respondent												Score	Rank
		1	2	3	4	5	6	7	8	9	10	11	12		
Design criteria	1	+	+		+	+	+	+	+	+	+	+	+	11	a
	2								+	+				3	i
	3		+		+	+	+	+	+	+	+	+	+	10	b
	4		+		+	+	+	+	+	+	+	+		9	c
	5								+					1	k
	6								+	+	+	+		4	h
	7					+			+	+	+	+		5	g
	8								+	+				2	j
	9													0	l
	10					+	+		+	+	+	+		6	f
	11					+	+	+	+	+	+	+		7	e
	12		+			+	+	+	+	+	+	+	+	8	d

Criteria are kept in order according to the summation value of crosses.

a. The simplicity of mechanism, operation, and form
b. Incorporation of automatic shuttle propulsion
c. The controlled beating of the weft
d. Easily adjustable take-up motion in conjunction with let-off motion synchronized with beat up motion.
e. The capability of weaving diverse fibers and materials like jute fiber to gunny bags, silks, and bandage materials for medical application
f. Provision for dobby/jacquard attachment.
g. Possibility to vary loom size and capacity
h. Easy manufacturability and low cost with standardized interchangeable components

i. Easy knock down and reassembly
j. Lightweight.
k. Auto sequencing system for healds.
l. Multiple shuttle box

From this sequence, it is evident that the mechanical shuttle propulsion takes the principal precedence, simplicity of the mechanisms, operations, and form, and easily adjustable take up over the other factors lower the sequence.

The factors h, i, j, and k will need more mechanisms to make them a reality but will make the loom unsuitable for female weavers. Still, factor j is the possibility of weaving diverse fibers and materials like jute fiber to gunny bags, silks, and bandage materials for medical application can be solved to a greater extent. Factor l has the problem that the loom cannot be made lighter after a specific limit since too light a loom will hinder the beat-up motion and the loom's stability. It will also result in increased vibration.

Based on the above, it was decided to eliminate factors h, i, and k. However, alternatives were considered and evaluated for all these factors during sub-system development.

3.6 Product Brief

Based on the analysis of the data collected and deductions from the design brief for the designing of the semi-automatic handloom, the following Product Brief is arrived at:

Human Factors:

a. It should provide continuous comfortable weaving for hours and reduce fatigue compared to other looms.
b. Should need minimum effort to operate the loom.
c. Operations should follow and reinforce inherent human capability.
d. All grips are to be designed to take into account human limitations.
e. Provides for easy ingress and egress by the weaver to the loom seat
f. An appropriate integrated seating arrangement with the structure.
g. It should be easy to maintain and repair.
h. It should reduce vibration and noise, and dust problems.
i. Provision for fixing light for illumination

Structural aspects

a. It should be a frame loom and sturdy enough to withstand rigorous use.

b. Should possibly use existing angular/tubular structural members for easy availability and manufacturability. Minimum parts should be used to construct the loom.
c. It should be easily disassembled and reassembled, and the members should provide compact packing for transportation.
d. The structure should not require expensive machineries for its manufacturing for a cost-effective manufacturing process.

Technical aspects

a. It should accommodate a longer length of the warp.
b. The loom's width should accommodate most of the everyday items of daily use.
c. Manual shedding for easy changeability of design is to be incorporated and provide simple structural design.
d. The shuttle needs to be propelled automatically.
e. Automatic take-up motion with easy adjustability for pick spacing should be incorporated. It also provides for take-up disengagement when the loom is mended for broken ends
f. The tension-activated oscillating backrest is required.
g. Automatic temple motion needs to be incorporated
h. Existing reed, healds, shuttle, pirns etc. should be possible to use.
i. Extra ornamentation design

Aesthetics

The visual aesthetic of the loom should inspire working on the loom. Also, it should look sleek to attract the weaver in terms of form and color, unlike traditional handloom's heavy and complex form.

Marketing aspects

a. It should be a high-productivity commercial loom to generate gainful income for the weaver.
b. It should be workable with existing preparatory machines like warping drums etc.
c. It should be targeted at centralized handloom production centers and marketable to an individual weaver.

Safety aspects

a. All moving parts are to be covered with safety guards.

b. All edges should be treated to prevent injury/scratches/bruises during weaving.

Packaging and transportation aspects

a. All parts are to be fit into less number of packets.
b. All parts are to be smaller to fit into small utility vehicle like TATA-407 and shipping container.
c. All parts are to be fit by keeping safe distance with level to avoid damage during transportation.

3.7 Feasibility study

Assessment of potential risks and their solution has been analyzed in technical feasibility. Operational feasibility and schedule feasibility have not been considered in the study. It has been planned to obtain technical solutions for the questions below while conceptualizing the design through the design tree approach.

- Is productivity improved?
- Is it possible to assemble and disassemble the loom?
- Is it easy to carry out maintenance and repairing?
- Is it convenient to use?
- Is it possible to transport easily with easy packaging?

Economic feasibility was studied concerning the cost of existing handloom and the approved cost of handloom for the subsidy by the Government of India. Research also considered the cost-benefit of the product.

The technical and economic feasibility of the semi-automatic loom has been found acceptable.

The National Aeronautics and Space Administration (NASA) has checked technology readiness, especially where making and trial prototypes is impossible. It was studied to incorporate the process to make the product ready to use without many iterations.

3.8 Technology Readiness through Technology Readiness Level (TRL)

Introduction to Technology Readiness Level:

TRL is a maturity scale measured in ordinal scale. TRL is part of the technology readiness assessment (TRA). TRL evaluates an essential component of risk, i.e. the maturity of critical elements means readiness or ability to perform as part of a more extensive system of technologies. It is done in multiple stages throughout its lifecycle. In general, these technologies are called critical technologies. TRA inform the state of technology development and identify potential risk or concerns. TRA does not measure or assign a risk level to a project or assess the ability to achieve system cost, schedule, or performance goals. TRA is done before development begins to avoid development delay and reduce development costs. TRA results can inform other assessments and planning activities, such as cost and schedule estimates, risk assessments, and technology maturation plans. The TRL scale consists of 9 scales, as below.

1) Basic **principles observed** and reported
2) Technology **concept** and/or application formulated
3) Analytical and experimental **critical function** and/or characteristic **proof of concept**
4) Component and or breadboard **validation in laboratory environment**
5) **Component** and/or breadboard **validation in relevant environment**
6) **System/subsystem model** or **prototype demonstration in a relevant environment**
7) **System** prototype demonstration in an **operational environment**
8) **Actual system** completed and qualified through **test and demonstration**
9) **Actual system proven** through successful mission operations

Some organizations have tailored the TRL definitions at each level to suit their product development applications like TRLs Supporting Information for Hardware and Software.

OECD (Organization for economic co-operation and development) has used all TRLs in four stages as below

1) Basic research – TRL 1-3
2) Development – TRL 3-5
3) Demonstration – TRL 6-7
4) Early deployment – TRL 8-9

Similarly, EIB (European investment bank) have used all TRLs in four stages with a different name as below

1) Research TRL 1-3
2) Development TRL 3-6
3) Innovation TRL 6-8 and
4) Production support TRL 9

HLG-KETs (High-level expert group – Knowledge enabling technology) used all TRL in three pillars with a base of fundamental research

- Fundamental research in TRL 1

- Pillar 1: Technological research in TRL 2-4
- Pillar 2: Product demonstration in TRL 5-8
- Pillar 3: Competitive manufacturing in TRL 9

Multi KETs or cross KET products are also used to assess idea to maturity. Based on the ARPA-E guide, we found an alternate to TRL by combined use of product development plus manufacturability.

The lowest TRL present determines the TRL of the system due to the integration effect. The TRL of every system, subsystem, and component, all of these elements can be at a higher TRL, but if they have never been assembled as a unit, the TRL will be lower. How much lower depends on the complexity of the integration. US Air force research laboratory has developed a **technology readiness calculator** (TRL Calc) executed through a series of questions and exit criteria for each TRL, allowing for a qualitative assessment of partial completion of a TRL based on the number of criteria satisfied. Fulfilling these criteria needs evidence and documents like test reports, analyses, and other assessments.

If the technology is not mature, the program should either consider using alternate mature, cost-effective technology or modify it based on the user's need.

Limitation of TRAs and TRLs

1) Limited shelf life
2) One size fits all approach is not feasible
3) Subject to the availability and makeup of the assessment team lead and its members
4) Subject to interpretation, experience, culture, or organizational bias
5) Evidence used to render a professional opinion is only as good as the artifacts, analyses, test reports, and relevant important information provided and relied upon
6) The linear approach to research, no concurrent engineering, challenging to assess multi-technology process (Lack of attention to setbacks in technology maturity)
7) Single technology maturity approach
8) Focus on product development rather than manufacturability, commercialization, and organizational changes
9) No context specificity of TRL scales
10) TRL metric is ordinal

Advancements in technology can pose challenges in applying TRAs. Organizational experience, culture, and bias can affect TRAs, depending on credible data quality and availability.

There are Research and Technology Organizations (RTOs) for intermediate support for interaction between disciplines with a trans-disciplinary and user-centric approach to solve societal challenges as below.

1) Binding various technologies together
2) Connecting one technology to various applications useful to different industrial contexts
3) Connecting technologies to non-technological disciplines incorporating the user perspective into development while looking at solutions
4) Support by resource person of various disciplines

Feature of intermediate support of RTO.

1) Basic research to applicable solution
2) Research infrastructure
3) Support policy making
4) Help develop existing products and processes to better suit industry and consumer needs.
5) Train and educate experts

TRL as a review tool for decision making to fund by EU (Focused on TRL 1-3/4)

1) Fundamental research 100% fund / Industrial research 50% fund / Experimental development 25% fund
2) Manufacturability and commercialization
3) Implications due to a temporary stoppage, scaling, and financial & commercial viability

Table 3.2: 6 steps to producing credible TRA

Step	Best practices	Associated tasks
1	Design the overall technology maturity assessment strategy for the program or project. Identifies all the technology maturity assessments for the overall program strategy throughout the acquisition, including guidance on reaching an agreement with stakeholders on the scope and schedule	• The technology needs of a program are well-understood, and the assessment strategy reflects those needs. • The schedule and events needed to conduct assessments were discussed, developed, and documented in one or more strategy documents • The technology maturity assessment strategy is aligned with the systems engineering plans.
2	Define the individual TRA's purpose, develop a TRA plan and assemble the	• A charter, charge memorandum, or similar instrument was developed to determine the TRA's purpose, required level of

	assessment team. Includes developing a plan for a specific assessment of critical technologies and criteria for selecting the team that will conduct the TRA, including agreements such as statements of independence	detail, overall scope, TRL definition and who will receive the TRA report. • The expertise needed to conduct the TRA and specific team members who are independent of the program were determined • The assessment approach was outlined, including appropriate TRL calculations (if used) • An approach for how the data is to be documented and information reported was defined • A plan for handling how dissenting views were identified • Pertinent information needed to conduct the TRA was obtained
3	Select critical technologies Includes the criteria and steps to identify and select critical technologies for evaluation; responsible parties facilitating the selection of critical technologies may include the specific organizations, people, and subject matter experts with crucial knowledge, skills, and experience	• The program's purpose, system and performance characteristics, and system configurations were identified in a technology baseline description document • A work breakdown structure, process flow sheet, or other documents that characterize the overall system, subsystems, and elements were used to select critical technologies • Programmatic and technical questions and the technology's operational environment were used to determine if technology was critical • The relevant environment for each critical technology was derived from the operational environment
4	Evaluate critical technologies Includes the criteria, analytical methods, steps, people, and guidance used to facilitate the evaluation of critical technologies, the sources and data, analysis, test demonstrations, test environments compared to derived relevant environments, pilots, simulations, and other evidence used to evaluate the maturity and readiness of critical technologies, the agreement of the program manager, technology developer, and TRA lead on what constitutes a specified TRL level, goal or objective	• TRLs or another measure were used as a common measure of maturity • Consistent TRL definitions and evidence needed to achieve the designated category or TRL were determined before the assessment • The assessment clearly defined inclusions and exclusions; the assessment team determined whether the test articles and environments were acceptable • The assessment team interviewed testing officials to determine whether the test results were sufficient and acceptable • The assessment team documented all pertinent information related to their analysis
5	Prepare co-ordinate and submit TRA report Includes the elements to be included in the TRA report and how the report is developed, submitted for initial and	• An official report was prepared that documented actions taken in steps 1-4 above • Official comments on the TRA report were obtained, and dissenting views were

	final review, and communicated; also includes how dissenting views are addressed, documented, and reported and who is involved	explained • Suppose the TRA was conducted by the technology developer or program manager for their own internal use where an official report is not required. In that case, it should be documented for future reference and use. It may include a TRA self-assessment conducted during early development and later used as a reference source to ascertain initial risks
	Using TRA results and developing a Technology Maturation Plan Describe how technology developers, program managers, and governance bodies use the TRA results to make informed decisions, how potential risks and concerns are identified, and the use of such information in other program risk assessments such as cost and schedule. Includes steps and activities for developing a plan to mature critical technologies that have been assessed as immature; uses the TRA results and other information to establish a road map for maturing technologies to a designated or higher technology readiness level.	• TRA results were used to make decisions about the program's development priorities • Program management identified risks and concerns related to the TRA were provided as inputs to risk, cost, and planning efforts • A technology maturation plan was developed to track progress toward higher technology maturity levels for troubled or selected technologies

High-quality TRAs

Table 3.3: Characteristics of high-quality Technology Readiness Assessments (TRAs)

Key characteristics	Description
Credible	Assessment design, execution, and reporting activity consider understanding the requirements, critical technologies, relevant or operational environment, and integration and interaction with other technologies or dependencies (i.e., timelines). TRA lead, subject matter experts, and practitioners have the relevant experience and knowledge to perform in their designated role
Objective	Judgments, decisions, and actions surrounding the assessment and TRA report are based on objective, relevant and trustworthy data, analysis, and information; free from internal and external organizational bias or influence
Reliable	Uses disciplined processes that facilitate repeatability, consistency, and regularity
Useful	Technology developers, system integrators, program managers, or governance bodies understand information; it has sufficient detail

	and is timely, and can be acted upon

Four steps to evaluate Critical Technologies

1) Agree on the Technology Readiness level matric and definitions
2) Assemble the Assessment team
3) Evaluate the evidence and determine a TRL rating for each critical technology
4) Document the evaluation of each critical technology by preparing a TRA report

Also, there is a checklist that can be used to evaluate Critical Technologies

1) The assessment team (TRA team, program manager, and governance body) verified that the test article and the relevant or operational environment used for testing were acceptable and validated that the results were sufficient.
2) Credible and verified information was used as evidence for the assigned TRL, such as requirement documents, analysis, test reports, and environmental test considerations.
3) Objective, independent review teams conducted the TRL assessment, particularly for decision point or stage-gate reviews by governance bodies.
4) The TRL rating of each critical technology was documented, including a summary, supporting documentation, and justification for the assigned TRL.
5) Technologies should be at TRL 6 or 7 before integrating into larger acquisition programs at the system level.

Use of TRA report for maturing technologies

1) Learn about specific aspects of technology development (Finding gaps or bottleneck areas)
2) Gather evidence to continue development efforts or initiate steps towards using an alternative or backup technology
3) Determine whether critical technologies are ready for a TRA for governance bodies at an upcoming decision point.

TRL can be evaluated as shown in Figure 3.1 by providing rating and score with a weightage factor to each evaluation criteria.

Evaluation Criteria	WT. Factor (%)	Proposal A		Proposal B		Proposal C	
		Rating	Score	Rating	Score	Rating	Score
A. Technical Requirements:	25						
1. Performance Characteristics	6	4	24	5	30	5	30
2. Effectiveness Factors	4	3	12	4	16	3	12
3. Design Approach	3	2	6	3	9	1	3
4. Design Documentation	4	3	12	4	16	2	8
5. Test and Evaluation Approach	2	2	4	1	2	2	4
6. Product Support Requirements	4	2	8	3	12	2	8
B. Production Capability	20						
1. Production Layout	8	5	40	6	48	6	48
2. Manufacturing Process	5	2	10	3	15	4	20
3. Quality Control Assurance	7	5	35	6	42	4	28
C. Management	20						
1. Planning (Plans/Schedules)	6	4	24	5	30	4	24
2. Organization Structure	4	4	16	4	12	4	16
3. Available Personnel Resources	5	3	15	3	20	3	15
4. Management Controls	5	3	15	3	20	4	20
D. Total Cost	25						
1. Acquisition Price	10	7	70	5	50	6	60
2. Life Cycle Cost	15	9	135	10	150	8	120
E. Additional Factors	10						
1. Prior Experience	4	4	16	3	12	3	12
2. Past Performance	6	5	30	5	30	3	18
Grand Total	100		476		516 *		450

* Select Proposal B

Figure 3.1.: Sample 'Source evaluation

Technology readiness level is reported by TROs with a report as shown in Figure 3.2 at every stage.

EXECUTIVE SUMMARY

Briefly state who requested the Technology Readiness Assessment (TRA), what organization was responsible for conducting the TRA, what technology was assessed. Provide a summary table of the critical technologies and corresponding Technology Readiness Levels (TRL) determined during the review.

INTRODUCTION

Background

Provide project/program overview and background information (i.e., general description of the program and the technology system, including the critical technologies to be assessed).

Purpose and Scope of the TRA

Provide an explanation of why the TRA was conducted (i.e. program management's review for maturing technologies, TRA required for a decision point, etc.), and scope of the assessment. Reference applicable decision memos and planning documents.

TRA Process

Provide an overview, and plan of actions and milestones to conduct the TRA. Reference planning documents.

RESULTS

Provide the following for each critical technology assessed:

• Technology Reviewed: Provide a detailed description of the technology that was assessed. The level of detail can vary depending on the phase of development, design characteristics, and scope of review. Organizations should strive to provide a sufficient amount of information to facilitate an understanding of the technology assessed.

• Function: Describe the functions of the critical technologies.

• Relationship to Other Systems: Describe how the critical technologies interface with other systems.

• Development History and Status: Summarize pertinent development activities that have occurred to date on the critical technology.

• Relevant Environment: Describe relevant parameters inherent to the critical technology or the function it performs as it relates to the intended operational environment.

• Comparison of the Relevant Environment and the Demonstrated Environment

Describe differences and similarities between the environment in which the critical technology has been tested and the intended environment when fully operational. The demonstrated environment must correspond to the identified relevant environment for the TRL to be justified.

• Technology Readiness Level Determination

State the TRL determined for the critical technology and provide the basis justification for the TRL.

• Operational Requirement: Describe the required/traceable system functional performance and enabling features for the critical technology elements.

ATTACHMENTS

Include the following planning documents:

• TRA Plan
• Supporting documentation for identification of critical technologies
• Completed tables: TRL Questions for critical technologies
• List of support documentation for TRL determination
• TRL Summary table
• Lessons Learned
• Team biographies

Figure 3.2: Technology readiness assessment report template

Process followed by Dept. of Defense, USA shown in Figure 3.3 by accommodating TRL in the process.

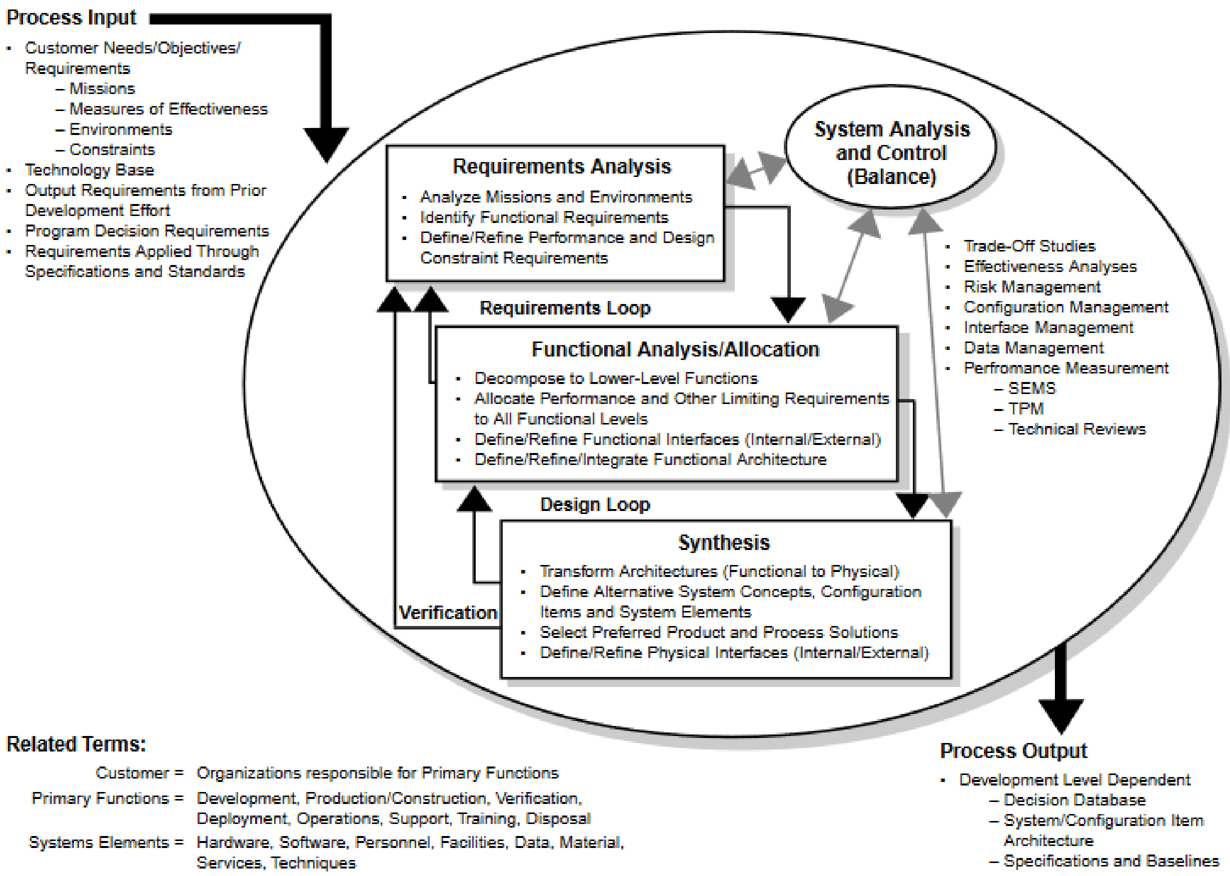


Figure 3.3.: The Systems engineering process by Dept. of Defense, USA

TRL in simplified form shown in Figure 3.4 to 3.7 to make smooth review process to check design from requirements to verification.

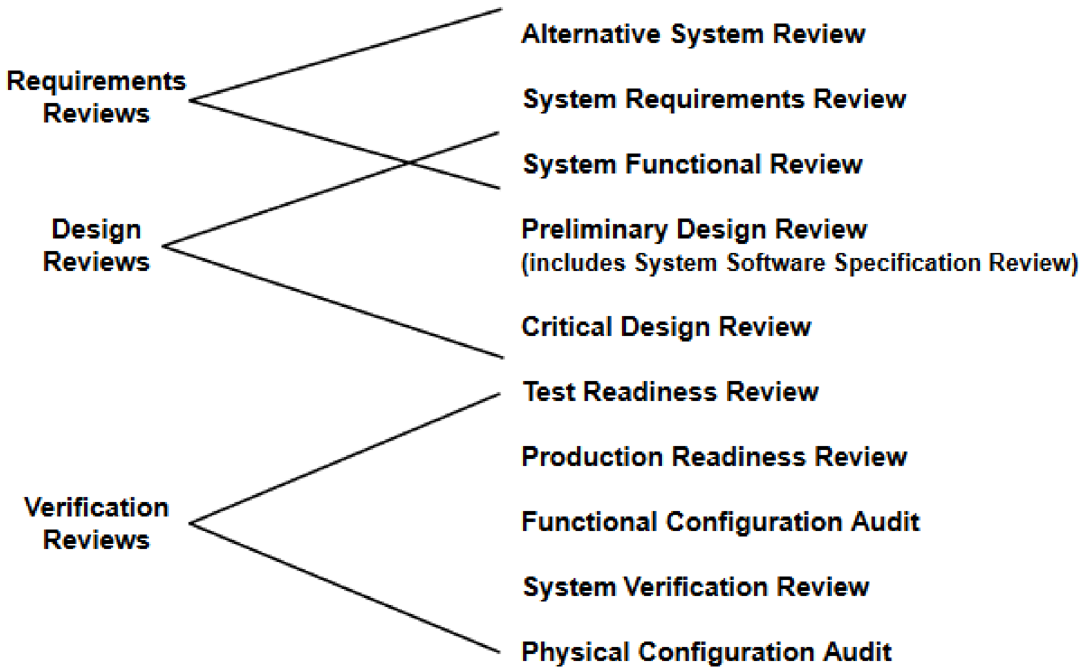


Figure 3.4: Typical system-level technical reviews

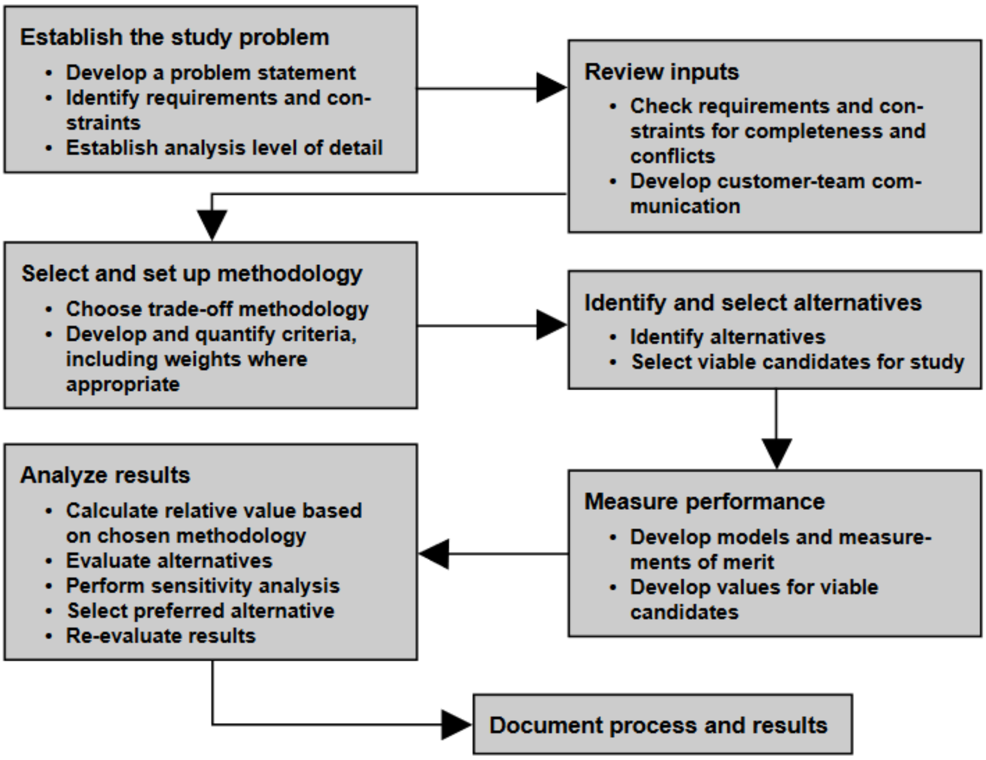


Figure 3.5.: Trade study process

System Requirements Review (SRR)	System Functional Review/Software Spec Review(SFR/SSR)	Preliminary Design Review (PDR)
• Mission Analysis completed • Support Strategy defined • System options decisions completed • Design usage defined • Operational performance requirement defined • Manpower sensitivities completed • Operational architecture available and reviewed	• Installed environments defined • Maintenance concept defined • Preliminary design criteria established • Preliminary design margins established • Interfaces defined/preliminary interface specs completed • Software and software support requirements completed • Baseline support/resources requirements defined • Support equipment capability defined • Technical architecture prepared • System defined and requirements shown to be achievable	• Design analyses/definition completed • Material/parts characterization completed • Design maintainability analysis completed/support requirements defined • Preliminary production plan completed • Make/buy decisions finalized • Breadboard investigations completed • Coupon testing completed • Design margins completed • Preliminary FMECA completed • Software functions and architecture and support defined • Maintenance tasks trade studies completed • Support equipment development specs completed

Critical Design Review Test Readiness Review (CDR/TRR)	System Verfication Review/ Functional Configuration Audit (SVR/FCA)	Physical Configuration Audit (PCA)
• Parts, materials, processes selected • Development tests completed • Inspection points/criteria completed • Component level FMECA completed • Repair level analysis completed • Facility requirements defined • Software test descriptions completed • Hardware and software hazard analysis completed • Firmware spt completed • Software programmers manual completed • Durability test completed • Maintinability analyses completed • Qualification test procedures approved • Producibility analyses completed	• All verification tasks completed • Durability tests completed • Long lead time items identified • PME and operational training completed • Tech manuals completed • Flight test plan approved • Support and training equipment developed • Fielding analysis completed • Provisioning data verified	• Qualification testing completed • All QA provisions finalized • All manufacturing process requirements and documentation finalized • Product fabrication specifications finalized • Support and training equipment qualification completed • All acceptance test requirements completed • Life management plan completed • System support capability demonstrated • Post production support analysis completed • Final software description document and all user manuals complete

Figure 3.6.: Sample event-based Schedule Exit Criteria

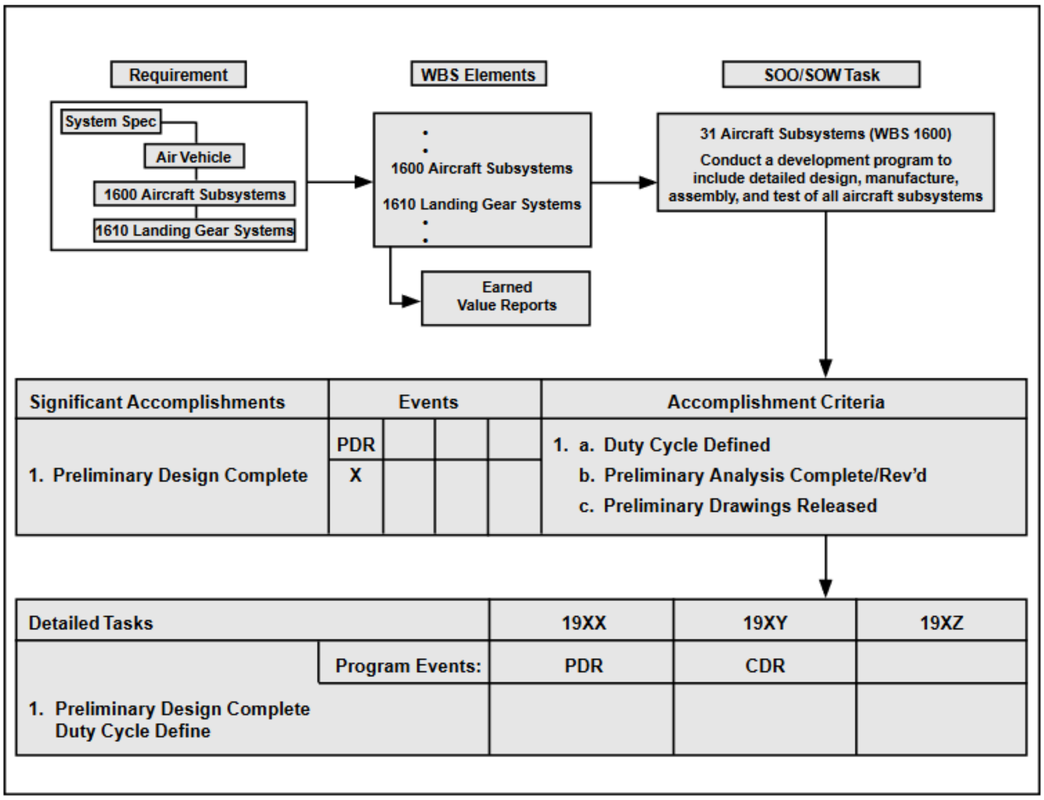


Figure 3.7.: Sample Event-based detailed schedule inter-relationships

Literature Review on Technology Readiness Level (TRL)

Literature is classified into four categories: Technology readiness level, and theoretical papers are critically reviewed. At the Technology readiness level, theoretical papers related to product design are reviewed. Then, practical papers on product design are reviewed at the Technology readiness level, such as case studies. Finally, practical papers on TRL are reviewed from other than the product design area.

i) Technology Readiness level (TRL)

"John C Mankins et al. 6 (2002) highlighted the strategic research and technology analysis for both commercial and government mission with a higher-order approach called ITAM – Integrated technology analysis methodology with a contextualized definition of TRL level with R&D degree of difficulty [82]. It is assessed through an integrated technology index (ITI); whereas

Individual Technology Index = ΔTRL x R&D^3 x TNV; where TNV is Technology need values, and

Integrated technology index (ITI) = $\frac{\Sigma\text{subsystem technologies } (\Delta\text{TRL x R\&D3 x TNV})}{\text{Total no of subsystems technologies}}$

"John C Mankins et al. 6 (2007) have reviewed the papers from 1977 to 2007. System developments face three significant challenges in any project, i.e., performance, schedule, and budget. It is crucial to reduce the uncertainty in all three challenges in project management. The effects are cost overrun, schedule delays, and steady erosion of initial performance objectives. It requires documenting all the assessments of technology readiness and risk by analyzing key points in the program's life cycle.

Key data for effective TRAs

- Performance objectives (Engineering measures of performance, such as mass, as well as operational measures of performance such as cost, availability, MTBF)
- TRLs – evidence of achievement of each TR
- R&D degree of difficulty: to know bottlenecks
- R&D three scale is used.

TRL did not emerge all at once rather emerged in several stages

The right level of technology maturity through a Figure of merit.

TRL – Establishing the suitable matrices for these technology/systems developments is essential; these must include a variety of performance and Figures of merit (FOM). [83]"

John C Mankins et al. 3 (2009) mention the importance of TRL and risk matrix for individually assessed system-level assessment. However, he has proposed a better methodology named 'Technology readiness and risk assessment' by integrating TRL and risk matrix with a new scale called TNV (technology need value) scale [84].

Hernando Jimenez 2 (2014) highlighted the limitation of TRL in measuring technology maturation level at the system level. He emphasized integrating technology development and maturation to analyze the higher level of technology readiness in each level based on the fundamental concepts of system architecture like system architectures, abstraction, interfaces, and interaction by illustrating an emerging technology on the structural concept**,** i.e., Pultruded Rod Stitched Efficient Utilized Structure (PRSEUS) used in aeronautics. Bilbro uses a product-oriented work breakdown structure (WBS) to identify allocated technologies subjected to maturity evaluation using the TRL scale through technology **maturation** assessment (TMA). The work breakdown structure is a means of organizing system development activities based on system and product decomposition. If system architecture changes, a mature technology with TRL-9 may change to the TRL-4 level [85].

John C Mankins et al. 3 (2009) mention the importance of TRL and risk matrix for individually assessed system-level assessment. However, he has proposed a better methodology named 'Technology readiness and risk assessment' by integrating TRL and risk matrix with a new scale called TNV (technology need value) scale [84].

Jeremy Straub 7 (2010) emphasize the need for a higher TRL category, i.e., TRL-10, because NASA used this assessment to assess unproven technology. When we assess for proven technology, we need TRL-10 to assess the extended operations

TRL-10: Proven operations (MTBF Mean time between failure in repetitive operations)

TRL-9: System operational [86]

Edouard Kujawski (2013) analyzed and critiqued the system readiness level. Many researchers show that TRL and integration readiness levels provide system readiness levels. It has some flaws, so corrective action is suggested [87].

Alison Olechowski et al. (2015) have reviewed the papers on the last 40 years of TRL practices and discussed 15 challenges of TRL [88].

Shanquing Li et al. (2017) have presented a multi-dimensional assessment system to calculate TRLs from seven dimensions, i.e., requirement, design, implementation, verification, configuration, risk, and safety. Criteria for requirement and design are listed out [89].

Tobias Eljasik-Swoboda et al. (2019) have explored the use of artificial intelligence for innovation readiness assessment. It has connected the market readiness and innovation readiness for matchmaking. An automated online coach has been provided to use TRL instead of physical presence [90].

ii) TRL specifically for Product design

Jan Harmsen 1 (2013) focused on **sustainability** by considering people, the planet, and profit factors, then discussed a new process that is sustainable from the idea generation stage to commercial production by creating synergy between industrial by-products in the process of identifying TRL. It has been considered for all stakeholders like a government body, company, institute, society, and environment for open innovation to get the best knowledge from **academics and industry** by sharing risk and cost. A technology for commercialization is judged by discussion between the open innovation partners to get prior feedback. He has a 4D approach for a reliable design with a well-prepared start-up. He also alerted the risk associated with direct implementation and suggested starting with a 10^{th} size small plant in an extensive process [91].

Minfang Zhang et al. have described TRA and its application in the engineering development phase. Key engineering performance parameter is taken as a quantitative evaluation index to assess TRL. The calculation method of the technology risk index is presented concerning the degree of difficulty of technology [92].

Mark Jones et al. have given a framework to manufacturing organizations through manufacturing impact assessment to validate any technology investment in each TRL to reduce development investment risk and give development value advice [93].

M J Ward et al. (2011) have modified the TRL process based on manufacturing technology development in the aerospace sector with an industrial approach [94].

Steven Peters (2015) has proposed a new model to assess TRL for new manufacturing technologies [95].

Pierre C Vella et al. (2016) have discussed technology maturity assessment of micro and nano manufacturing processes and process chains based on the capability and weakness of individual processes and technology interfaces between them, inspired by the capability maturity model used in software engineering. Once individual processes are analyzed, pair those and check the combined maturity [96].

Jill C Madison et al. have described the application of TRL in advanced research and development by combining system engineering with technology and manufacturing readiness levels. He has proposed a tailor-made technology development process for smaller research-based projects [97].

Joao Rcardo Lavoie et al. (2017) discussed a ground theory analysis for improving R&D management through TRL. It has listed the various benefit of TRL and various issues of R&D in tabular format. The importance of TRL in R&D projects is also highlighted through a pie chart [97].

Rainer Hasenauer et al. (2016) describe the market readiness level for an innovating incubator considering the triple bottom line, i.e., social, ecological, and financial, of 57 companies [90].

Irene Spitsberg et al. (2013) discuss technology landscape mapping and technology scouting with an open innovation strategy at Kennametal [98].

Rosa G J et al. (2015) have presented a quality management system for suppliers to assess their quality readiness level in a low-volume industry based on the prioritization establishment tool NTCP-F (Novelty, technology, complexity, pace, fabrication/manufacturing). The automotive high-volume industry uses PPAP to evaluate their supplier [99].

Abdourahim Sylla et al. (2017) have assessed the bidding process through TRL to make a better offer for any enquiry received by the company [100].

iii) TRL applications on Product design

Hernando Jimenez 2 (2014) showed a new structural concept case study and assessed it through TRL-3 to TRL-7 in demonstrator & test environment to analytical model & performance prediction stages [85].

Zhitao Liu 8 (2014) has done a technology readiness assessment of small modular reactor (SMR) design but does not analyze point by point with each TRL level. He introduced the topic and highlighted main design options, sub-system details, technology evolution, systems & equipment, protections against field failures through Full fidelity integrated systems test (IST) [101].

Asa Fast-Barglund et al. 10 (2014) describe using TRL in designing a product with two case studies. The current theoretical framework of TRL is challenging to use in a manufacturing context. It is tough to justify an implementation solely based on technology. So, TRL is a helping tool to reach other goals but not a goal itself [102].

Iwan Inrawan Wiratmadja et al. (2016) describes the assessment of the manufacturing readiness level of railway wheels with a proper development model. MRL consists of 10 levels described by 90 criteria and 184 sub-criteria. Indicators assessed up to MRL-5 are cost and financing, process capability and control, quality management, workers, and manufacturing management criteria [103].

Abstract of TRL for Semi-automatic handloom

Handloom weaving is manual work without the involvement of an external power source. Design and development of semi-automatic handloom were carried out to improve productivity and quality of fabric woven. Handlooms have a unique competitive advantage over power loom because they can produce tailor-made products per the customer demand. This research was carried out for a metallic semi-automatic handloom with improved productivity. Newly designed semi-automatic handloom with automated picking take-up and let off the motion by synchronization with beat-up motion. Productivity was a key performance parameter in technology readiness assessment through the technology readiness level (TRL) scale. Productivity of handloom improves by 50%, from 30 picks/minute to 45 picks/minute.

Concise literature review of TRL related to Semi-automatic handloom

Many organizations focus on methodologies for organization development, whereas there were no such methodologies for technology development prior to the technology readiness assessment built by NASA. TRL helps to make better decisions to manage research and development [90]. Any system with new technology face three main challenges, i.e., performance, schedule, and budget. These challenges correlate to each other; if the required high-performance technology is required, then the cost will be high. Technology readiness level and risk matrix are key tools for smooth assessment flow to overcome the above three challenges. Technology readiness level alone has some limitations in some stages to improve research and development outcomes. Therefore, it is found that integrating the risk matrix with the technology readiness level can improve the technology assessment and also the associated risk in its life cycle [84]. TRL provides only the basic guidelines. Continual improvement is essential in TRL methodology, which addresses long-term technology needs and opportunities. TRL provides better results by blending with other methodologies on a case-to-case basis [82]. TRL is used to harmonize all technologies under the development of the system [93]. A graded systematic approach can be adopted for technology development and transfer for a multidisciplinary program with TRL [104]. TRL is used to evaluate technology readiness through quantifiable 'key engineering performance parameter' as an evaluation index. An evaluated technology performance risk index helps to know the degree of difficulty of the technology [92]. Process assessment can also be done with TRL. Processes need to be classified based on different elements for process assessment with a bespoke methodology and design assessment based on TRL with a matrix approach. Mostly individual technology or process falls in the “proof of principle” range with TRLs between 4 and 6. System level TRL falls drastically in case of gap in the individual process steps [92]. TRL effectively communicates the status of new technology [83]. TRL scale data was initially used for technology management to make high-cost decisions for development. Now, it is used in innovation and development [88]. Innovation will be successful if a huge target market is available and innovation is ready to fulfill the target market supported by an innovation readiness assessment method to increase success chances. TRL need someone to explain to put the level; therefore, they have worked to automate the assessment process [90]. Comparison of all models from the originating design with innovative features to get a comprehensive understanding based on the bidirectional assessment method, one in the longitudinal direction and the other in the transversal direction [105]. Cognitive automation strategies create a competitive advantage in prototyping and testing. Fast-Berglund tested a hypothesis on whether TRL methodology can be used in a production context or not [102]. Integration is an inherent sub-attribute of any technological innovation. A higher level of technology readiness can be achieved by generating the characterization of integration for each readiness level based on system architecture, abstraction, interfaces, and interaction. Most product-based organizations do not focus on manufacturing components; instead, they focus on integration. There is the advantage of benchmarking for a higher level of technology readiness. In the case of new development, getting a benchmark is impossible [85]. TRL started for the assessment of unproven technology. There is a need for a higher TRL category for proven technology [86]. TRL traditional calculators provide a scale from 1 to 9 to describe the maturity of the technology. This assessment method does not provide any further details for each level. Level 1 is the lowest, and level 9 is the highest level. This assessment method is useful and effective [90]. Direct use of TRL in manufacturing is problematic due to the precise interpretation of problems. In such cases, the assessment can be done indirectly by assessing the manufacturing technology [94]. TRL is used to evaluate technology readiness through quantifiable ‘key engineering performance parameter’ as an evaluation index. The technology performance risk index helps to know the degree of difficulty of the technology [92]. An idea can be converted into a successful and sustainable commercial product that society accepts, does not harm the environment, and makes a profit based on the Stage-Gate Innovation Pathway Model. Open innovation is a good way to obtain cost-effective novel solutions. A technology readiness level for process innovation is adopted. A unique method is provided for process concept design [91]. The learning from one sector to another has been abstracted to deploy the knowledge horizontally [90]. Assess the maturity of manufacturing technology in software engineering [96]. TRL was applied in a major construction project. TRL act as a management, communication, and tracking tool [106].

Chapter 4: Design and Development of Semi-Automatic Handloom

This chapter explains the semi-automatic handloom's design and manufacturing process through an alpha model followed by a beta model manufactured with readily available resources from the workshop of Department of Design, IIT Guwahati and few vendors.

4.1 Concept Design

The interaction matrix was followed to identify the current problem in handloom to overcome these problems; creative design methods are used, such as brainstorming after thorough literature and product review.

Based on the above process, a new prototype semi-automatic handloom was conceptualized which will be productive, cost-effective, and easy to transport through research by design methodology. Also, it will have a superior synchronization between the weaver, loom, and their environment.

Research by design is research through design, using the expression especially developed from the Dutch practice at The Faculty of Architecture in Delft. The concept has been used about the various ways in which design and research are generally interconnected when we produce new knowledge about the world through the act of designing.

The European Association of Architect Educations have defined research by design as follows.

Research by design is any kind of inquiry in which design is substantial part of the research process, which forms new insights, knowledge, practices and products come into being.

Research by design generates critical inquiry through design work that may include realized projects, proposals, possible realities and alternatives.

Research by design produces forms of output and discourse proper to disciplinary practice, verbal and non-verbal that make it discussable, accessible and useful to peers and others.

Research by design is validated through peer review by panels of experts who collectively cover the range of disciplinary competencies addressed by the work.

4.2 Structure Design

Based on the design methodology adopted, four possible concepts were generated for the structural part of the handloom. These are given below.

A. All enveloping structure

B. L channel structure
C. Rectangular tubular structure
D. C-Frame sheet metal structure

The above concepts were subjected to detailed analysis for their feasibility. The details of the same are given below.

4.2.1 Concept-A: All-enveloping structure

It is a tubular structure; as the theme indicates, the structure members form an envelope and outline all functional parts.

Advantages: It provides an utterly streamlined form. It also conveys the feeling of safety since moving parts like sley is within the structural members.

Disadvantages: Excess materials are required since the structure is duplicated and elongated in addition to the functional requirement. Also, during manufacturing, it will need sophisticated machinery; therefore, production costs will be high.

4.2.2 Concept-B: L channel structure

It is an L-channel structure, and as the theme indicates, the structure members are simple and outlined to fit all functional parts.

Advantages: It provides a general form. It also conveys the feeling of safety due to its strength since moving parts like sley is within the structural members.

Disadvantages: It will need sophisticated machinery for manufacturing; therefore, production costs will be high due to additional cost on various jigs and fixture. Mass production will be time taking.

4.2.3 Concept-C: Box frame structure / Modular knockdown type tubular structure

Instead of tubular elements, the structure of the loom is constructed with sheet metal formed into a box structure for the side and top cross bars. The front rest and backrest are also made out of sheet metal.

Advantages: From the aesthetic point of view, this gives a cleaner, un-clustered, and very sophisticated image to the loom. Also, the triangulation is taken care of by the structure itself. Producing in mass will reduce the cost.

Disadvantages: This concept for the structure will need plate cutting and bending machines, and the sheet metal will cost higher than the targeted price range of the loom. Handling requires special care.

4.2.4 Concept-D: C-Frame structure

In this concept, the theme is to base the structure on a C-frame and build the whole loom structure. The C-frame, in this case, is taken as the member comprising the sides and top cross bars.

Advantages: Here, the inherent strength of the C frame is utilized, and the construction becomes very simple. Also, it does not require to be manufactured with covered tubular members. It can be constructed with 25mmX25mm square and 25mmX 50mm rectangular members cut and welded to manufacture these structural members.

Disadvantages: it needs triangulation and modification of the C-frame to obtain an aesthetically pleasing form. Mass production will be time taking.

Another aspect is the acceptability of the loom by the users. Since this looks like a very light machine, common village weavers may accept it commercially for the structure and form.

Based on the evaluation of the above concepts, the third one based on Modular knockdown type tubular is taken for further development and detailing. Also, some of the convenient features from the other concepts were too incorporated into this concept.

The final concept has arrived from the Modular knockdown type tubular concept through

i. C-frame was modified to provide aesthetically pleasing form and triangulation in the structural design.
ii. A sheet metal box frame is introduced at the sides for triangulation between the modular knockdown type tubular and other members. This concept also provides surfaces for graphics.

It is not durable when metallic mechanism applied in wooden handloom as shown in Figure 4.1.

Figure 4.1: Metallic mechanism in wooden sley in fly-shuttle handloom

4.3 Sub-system Design

Based on the design methodology of the piecemeal design approach, the loom is considered a system comprising various sub-systems. All different sub-systems of the loom are explored separately by studying the existing mechanisms from different types of looms, irrespective of handloom or power loom. Based on this study, the systems compatible with the semi-automatic loom to be designed are adopted and considered for individual design development. Details of various sub-systems are illustrated below.

4.3.1 Shedding mechanism

The first sub-system of a loom is the shedding mechanism. Shedding is an operation that divides the warp sheet into two layers per the cloth's design pattern to place the weft yarn for interlacement. This mechanism is also the first in the sequence of primary motions of weaving.

There are various shedding mechanisms existing as follows.

i. Treadle and top roller reversing motion.
ii. Jack and lam tie-up
iii. Dobby
iv. Jacquard
v. Tappet shedding

Out of the above five mechanisms, the Jacquard type of shedding was accepted since these are suitable for structural designs and ornamental fabrics. The Dobby type of shedding is discarded as the jacquard type can perform a similar function. This attachment does not justify inclusion in a semi-automatic handloom as part of automation. However, being part of the handloom is essential as an additional device for ornamentation in fabrics.

In the case of the Jack and lam arrangement, it is the slow-acting mechanism. Since a semi-automatic handloom is productive, including Jack and lam will reduce the speed and productivity of the loom. Therefore, it is discarded. It exists in Shanti loom along with jacquard mounting provision.

Adding a tappet requires a secondary bottom shaft and reduction gearing in the Tappet mechanism. This mechanism will make the loom either operable as a pedal loom or has to be operated only with the hand (like Banarasi semi-automatic handloom), rendering either of the limb (upper or lower) useless in operating the loom. It will result in fatigue only in one limb. Also, the versatility of the loom for weaving designed fabric is lost.

Compared to all the other mechanisms, the first one is a manually operated treadle, and the top roller reversing motion is best suited for semi-automatic handloom design and adopted for this. Jacquard type of shedding is also kept as an attachment for ornamentation.

The treadle has been modified to provide a better ergonomic working posture.

4.3.2 Picking mechanism - shuttle propulsion

The second sub-system of a loom is picking, i.e., passing the weft yarn between the open warp shed. In the case of primitive looms, it is done by hand and is also known as a throw shuttle. However, our concern is only with the fly shuttle picking mechanism; hence we need to consider the method of shuttle propulsion. For this, there are several options available and studied as follows.

i. Manual shuttle propulsion is usually found in handlooms with overhead rope tying.
ii. Burmese type of shuttle propulsion.
iii. Mechanized automatic cone type of over-pick mechanism.
iv. Mechanized automatic lever type of under-pick mechanism.

v. Mechanized automatic cone under-pick mechanism.

Manual shuttle propulsion, commonly used in handloom, needs an overhead structure for the tie-up. Also, the degree of automation will be low with this type of shuttle propulsion since shedding is already left manual. This type of picking also demands more synchronous movement from the weaver and is more straining on the part of the weaver. Based on all the above, this type of shuttle propulsion is discarded.

The second type of shuttle propulsion used in Burmese type semi-automatic handloom is most suitable since it uses the motion of the sley for propelling the shuttle across the shed. It is also appropriate from the point of view of utilizing the existing parts like spindles and pickers. It also discards overhead structures required by the previous type of shuttle propulsion, which helps keep the structure light. Based on all these evaluations, this type of shuttle propulsion is selected.

The other three types of shuttle propulsion mechanisms iii, iv, and v need a bottom shaft fitted with reduction gearing and tappet mechanisms. This mechanism also requires higher energy for operation and is therefore discarded for the semi-automatic type of loom design. Another disadvantage is cost, which will be very high compared to other types.

4.3.3 Beat-up mechanism

The third sub-system of a loom is the beat-up mechanism. This system assists in bringing the last weft to the fall of the cloth by beating up the same. All looms use a reed mounted on the sley race and are reciprocated to and fro for beat-up except primitive handloom. The sweep of sley is not restricted in a conventional loom other than the fall of the cloth and heald. Also, the sley is hung overhead for swinging.

Controlling the sweep of the sley is necessary to obtain uniform beating force repeatedly and produce quality material without pick spacing variations through an automatic take-up mechanism. Also, the sley needs to be underhung to minimize vibration and keep the light structure of the handloom.

Based on the above analysis, in the present design case, the sley is selected for underhung, and its sweep is restricted by using a crankshaft. The flywheel-type crankshaft aims to restrict the sweep of the sley rather than conservation of momentum. The flywheel should be neither too heavy nor too light to solve the purpose.

4.3.4 Take up mechanization

Take up is another sub-system of a loom falling under secondary weaving motions. In the absence of take-up motion, continuous weaving is not possible. Various alternatives were studied and evaluated to adopt an appropriate take-up mechanism for the loom design; the same is mentioned below.

a. Negative manual take-up
b. 5-wheel take-up motion
c. 7-wheel take-up motion
d. The worm and worm wheel take-up motion.

Since negative take-up motion is unsuitable, it is rejected because it is manual and intermittent for the semi-automatic loom. It also provides no control on weft spacing.

In the case of 5-wheel take-up motion, being positive, automatic, and simple, the reciprocating movement of the sley actuates it. This take-up motion, in conjunction with the take-up guard, provides for different pick spacing and is found suitable for the loom design and adopted.

In the case of the 7-wheel take-up mechanism, it is more complex and will cost much higher. It also requires more energy to operate. Based on these, this mechanism is rejected.

Similarly, the worm and worm wheel take-up mechanism is rejected on the ground that its working is not superior to the 5-wheel take-up motion but needs provision of the shaft at a right angle to the cloth beam, thereby increasing the complexity of the loom.

4.3.5 Let-off mechanism

Let off is another sub-system of the loom and categorized as the second in the secondary weaving motions.

Let off mechanism works in conjunction with the take-up mechanism. The various alternatives available for consideration are

a. Negative let-off mechanism based on chain, lever, and dead weight
b. Negative let-off mechanism based on spring-loaded resistance
c. Positive let-off mechanism

The negative let-off mechanism is actuated by the tension generated due to the take-up of woven cloth by the positive take-up mechanism. The positive let-off mechanism is independent of the take-up mechanism and is mainly actuated by the reciprocating motion of the sley. It is much more complicated and requires many more different parts. So, It is more expensive. Since the loom to be designed is to be made simple, low cost, and easily operable and serviceable, the positive let oft mechanism is inappropriate in this context.

The spring-loaded negative let-off mechanism is better in conjunction with an oscillating backrest. It also does not require many parts like chain, lever, dead weight, and frequent adjustment during weaving. Based on the above comparison, the spring-loaded negative let-off mechanism is used in the loom. It has a wooden ruffel secured to the warp beam over which one rope is passed on two grooves, and the end of the rope is loaded with spring, and resistance is generated by loading the spring with the nuts and bolts provided for the purpose. Wherever take-up mechanisms were introduced without controlled beat-up, results were disastrous.

4.3.6 Oscillating Backrest

The shedding mechanism selected for the loom design is the treadle and top roller reversing mechanism. This type of shedding mechanism produces a center-closed shed, which results in tensioning the warp sheet during shed formation, and once the shed is closed, the warp sheet becomes slack due to tension relaxation. It affects the pick spacing by affecting the beat-up adversely. An oscillating backrest is used to compensate for this disadvantage of center-closed shedding.

In the case of a mechanized power loom, the backrest oscillates through a cam fitted on the crankshaft. However, for simplicity and cost reduction, a spring-loaded oscillating backrest is designed for the loom.

Here during the shedding, the springs of the backrest yield; thus, the extra length of warp is released for shedding, but immediately once the shedding is over and shed closed, the resultant slackness of the warp sheet is removed by the backrest since the springs exert tension on it

4.3.7 Temple motion

Another sub-system of a loom is the temple mechanism. The Temple mechanism is categorized in the third set of weaving motions as tertiary or auxiliary. This category of motion is essential for producing defect-free fabrics. Temple motion assists in weaving fabric of uniform width and unbroken selvedge. In normal handlooms, manual temples are used. These need a frequent adjustment with the fall of the cloth.

An automatic roller of the ring temple is used in the power loom. Ring temple is expensive and delicate. Therefore, the common roller-type temple is selected for the loom design. Here two numbers of spiked rollers are used on each side (left and right), and as the cloth is taken up after weaving, the rollers roll to release the woven cloth maintaining uniform width. The selvedge obtained is also unbroken.

These temples can be adjusted for different widths of fabrics and are fitted to the loom with the help of a leaf spring set to provide spring-back action. In case the sley hits the temples, because of the spring back action, the temples will not damage the sley.

4.4 Total System design

At this juncture of total system design, the various sub-systems developed are integrated into the concept design selected for the complete structure to achieve a unified system. Also, various human factors issues are addressed here too. The total system design evolved from the design exercise has the following features.

4.4.1 Human factors

Posture: The new adjustable seating system provides a comfortable sitting posture during weaving and facilitates the loom's operation. The new adjustable seating system is designed for height, distance from the loom, and width of the seat adjusted to facilitate 5th and 95th percentile weaver. Also, a forward tilt is provided to the seat for comfort.

To provide back support, as and when required, an adjustable backrest with a maximum tilt of 10 degrees from vertical (i.e., 90 + 10) is provided. Sheet metal and cloth is the material used for the seat.

Operation by the lower limb: Lower limb is used for shedding operation. However, in the conventional loom, treadles are used, which are un-ergonomic. To overcome this automotive type pedal is used with appropriate modification.

Hand grip: Once picking is automated, the weaver's hands are free to operate the sley. Now to provide ergonomic grip, a handle that swivels horizontally is located on the top of the sley.

Sound: It is reduced by enveloping and covering the shuttle box with a sound-absorbing sponge and covering layered with the sponge. The cover can be flicked open to attend to the shuttle box. Also, leather buffers are used to reduce sound from the impact of the shuttle.

Visibility: To facilitate detection of a fault in woven material, defused light is provided below the woven cloth nearer to the fall of the cloth as a slit from one selvedge to the other.

Safety: All gearings are enclosed with a cover to provide safety, Colour: The color of the loom is selected for a neutral effect on the weaver's eye to provide a feeling of lightness on the loom. White and light grey are such colors used for fixed parts. Yellow is used for moving parts, whereas bright orange is used for unsafe moving parts.

4.4.2 Operational aspects

In the loom designed, the shedding mechanism works independently. Handloom engages both the feet and facilitates mending the broken ends. Treadles are provided with two foot pedals (similar to the bicycle's).

The Burmese type of picking mechanism works in conjunction with the beat-up mechanism. When the sley is taken to the extreme rear position, the shuttle is automatically propelled through the shed over the race board from one shuttle box to the other.

The synchronization required for this is that the weaver needs to form the shed by depressing the treadle as per the weaving pattern.

Similarly, the take-up works in conjunction with the sley's reciprocating motion. When the sley comes forward, the pawl of the take-up mechanism comes forward, sliding over the take-up guard, and in the reversing motion pulls forward the ratchet wheel as per the setting of the pick spacing. Also, the take-up mechanism is modified to house all the five gear wheels on only two shafts. The ratchet wheel, compounded change wheel, and take-up guard are freely mounted to the emery roller shaft. The change wheel drives the stud wheel, which is compounded with stud pinion and mounted freely on the stud pin. The stud pinion drives the emery roller wheel fixed onto the emery roller shaft. Adjustment of pick spacing is possible through the lever mounted on the stud pin and secured to it with nuts and bolts. It holds the take-up guard in a fixed position.

Let off mechanism works in conjunction with the take-up mechanism. The positive take-up of the woven materials generates tension on the warp sheet, and when this tension exceeds the resistance provided by the spring-loaded let-off mechanism, it let-off the required amount of warp.

The temple mechanism also works when the cloth is taken up. The rollers inside the temple mechanism allow the cloth to come forward for rolling onto the cloth roller.

Since loaded with spring, the oscillating backrest keeps the warp sheet in uniform tension. It only allows yielding the let-off mechanism after it has reached its limit and immediately takes up any slackness resulting from shed closing.

4.4.3 Manufacturability

The alpha model of the loom is designed to be manufactured out of 25mm X 25 mm square and 25mm X 50mm rectangular MS tubular structural elements with 2 mm thickness. It is done because laser cutting and sheet metal forming parts need to order in lots of 50 minimum to the vendor. Therefore, the alpha model manufactured with rectangular MS tubular structure checks all functional aspects. The beta model of the loom is designed to be manufactured from sheet metal simple formed parts which can be achieved by a CNC bending machine after cutting the blank in a laser cutting machine after a successful trial of the alpha model.

Parts are cut, welded, and drilled holes for fasteners. It needs only simple tool room machines like a power saw, arc welding machine, grinding machine, and drilling machine. For other parts, gears are to be procured ready-made from vendors, and other items can be produced using a lathe machine. A spray painting machine is used for painting the loom. For the sley made from wood, ordinary carpenter's tools are used.

Based on all these, it is evident that the loom can be easily manufactured in a moderately equipped workshop.

4.4.4 Serviceability

The loom virtually needs no regular servicing except lubrication of its very few moving parts like sley support, footstep bracket, crankshaft, take-up mechanism, let-off mechanism, and foot pedals for shedding. In case of wear and tear, all parts can be readily manufactured or repaired in any small workshop.

4.4.5 Cost

The handloom design uses minimum material; these materials are readily available and can be manufactured in the nearby available fabricator/workshop. The cost of the loom will be within the targeted range and hence can be marketed to the target group. Also, the cost can still be reduced if a larger batch is produced. A larger batch is indicated to be 50 looms per batch. This loom is designed to be easily manufactured and maintained at an affordable cost.

The cost of a traditional wooden handloom (38” width) shown in table 4.1 is 37500₹ as of FY 2020, out of which 25000₹ is for wood material and 12500₹ for purchasing essential accessories.

Table 4.1: Wood required for traditional handloom

SA	Size	Qty
Frame	4" x 3" x 6 ft	4
Frame	2" x 2" x 7 ft	2
Frame	2" x 3" x 6 ft	3
Frame	2" x 3" x 5 ft	2
Frame	2" x 3" x 3 ft	2
Frame	4" x 3" x 3 ft	2
Sley	2" x 3" x 7 ft	1
Sley	2" x 2" x 7 ft	1
Sley	2" x 2" x 5 ft	1
Sley	3" x 1" x 6 ft	1
Sley	4" x 1" x 6 ft	1
Naraj	5" x 1" x 4 ft	1
Warp beam	4" x 4" x 7 ft	1
Cloth beam	3" x 3" x 6 ft	1
Jacquard guide	2" x 3" x 6 ft	2
Seat	2" x 1" x 8 ft	1
Seat	2" x 1" x 4 ft	2
Seat	2" x 1" x 4 ft	1
Stool	7" x 1" x 7 ft	1

The cost of a new Semi-automatic handloom (52" width) is 90000₹ as of FY 2020. This cost is high as it also includes warping drum and creel along with it.

The allowable cost of the machine and related equipment by the Government of India as per the technology up-gradation scheme has shown in Table 4.2.

Table 4.2: Allowable cost of the machine and related equipment by the Government of India

	Items	Cost
a)	Pneumatic jacquard system for a set of 4 handlooms	Rs.40,000/-
b)	Motorized jacquard on the existing handloom	Rs.15,000/-
c)	Take-up & let off motions on the existing handloom (including fitting charges)	Rs.5,000/-
d)	Multiple box motion	Rs.3,000/-
e)	Multiple buti weaving sley	Rs.7,000/-
f)	Twin cloth weaving mechanism (including fitting charges)	Rs.5,000/-
g)	Jacquard with complete set including installation	Rs.15,000/-
h)	Dobby	Rs.5,000/-
i)	Healds reeds, bobbins, shuttles etc. (set)	Rs.4,000/-
j)	Frame loom a) upto 60" b) above 60"	Rs.25,000/- Rs.40,000/-
K)	Asu Machine (Mannual)	Upto Rs.10,000/-
l)	Asu Machine (Motorized)	Upto Rs.30,000/-
m)	Warp beam & fabric beam	Upto Rs.5,000/
n)	Normal warping machine	Upto Rs.25,000/
o)	Motorized warping machine	Upto Rs.45,000/
p)	Motorized Pirn Winding machine	Upto Rs.3,000/
q)	Motorized Prin- cum bobbin/ dubba Winding machine	Upto Rs.4,000/
	Street Sizing Kit (brush, sticks, spray gun etc.)	Upto Rs.10,000/
r)	Any other item recommended by the Expert Committee and approved by the DC (Handlooms)	

4.5 Design conceptualization and Prototype Development

Detailed products are shown in the subsequent pages in chronological order, from the L channel concept as the base model to the C-Frame concept as the alpha model to the beta model.

4.5.1 Reverse engineering of Shanti loom with L channel structure

This design research project was initiated based on the above understandings. Instead of initiating a new design for an appropriate semi-automatic handloom, work was started considering an existing semi-automatic handloom known as the Shanti loom (1990), which was fabricated in mild steel with a wooden sley [15]. L channel structure applied with the Shanti Semi-automatic loom, an alternative to wood in the traditional fly-shuttle loom, was designed to increase the utility of the handloom by increasing its productivity and valuable life [15]. Shedding was independent of Picking and Beat-up motions to facilitate weaving structural design cloth and extra ornamentation. Picking was manual similar to the traditional fly-shuttle type, and beat-up was synchronized with the take-up motion and, in turn, with the let-off motion. Temple motion worked in conjunction with the automatic pick-up of cloth.

Aesthetics and ergonomics aspect was considered during design conceptualization. Other functional aspects were synchronization of various primary, secondary and tertiary motions. Shanti loom had the disadvantage of having the same picking difficulties as in traditional handlooms and fabrication and machining due to the shape of the L-section.

The new semi-automatic handloom consists of the following mechanisms motion-wise shown in Table 4.3.

Table 4.3: Mechanisms available with the various motions of the loom

Primary motions	**Available Mechanisms**	**Traditional handloom**	**Shanti loom**	**De-sign loom**
1. Shedding	Treadle and pulley	√	√	√
	Jack and lam			
	Dobby			
	Jacquard			
	Tappet			
2. Picking	Manually propelled	√	√	
	Burmese over pick			√
	Tappet under pick			
3. Beat-up	Overhung sley – uncontrolled sweep	√		
	Underhung sley – controlled sweep		√	√
Secondary motions				
1. Take-up	Manual	√		
	5-wheel Take-up motion with two shafts			√
	5-wheel Take-up motion with three shafts		√	
	7-wheel Take-up motion			
	Worm & worm wheel Take-up motion			
2. Let-off	Manual	√		
	Chain, lever, and dead weight			
	Rope and spring		√	√

Tertiary motions				
1. Temple	Manual wooden temple	√		
	Roller-type temple mechanism		√	√
	Ring temple			
2. Oscillating Backrest	Spring-loaded oscillating backrest	NA	NA	√
	Cam operated oscillating backrest	NA	NA	
Structure 1. Wooden frame 2. Metallic frame		√		
	L channel structure		√	
	Rectangular tubular structure			
	C type frame			√
	Solid block structure			
Rate of mass production of loom and durability		Low	Medium	High

Various views of Shanti looms with L channel steel structure are shown in figure 4.2 to 4.6.

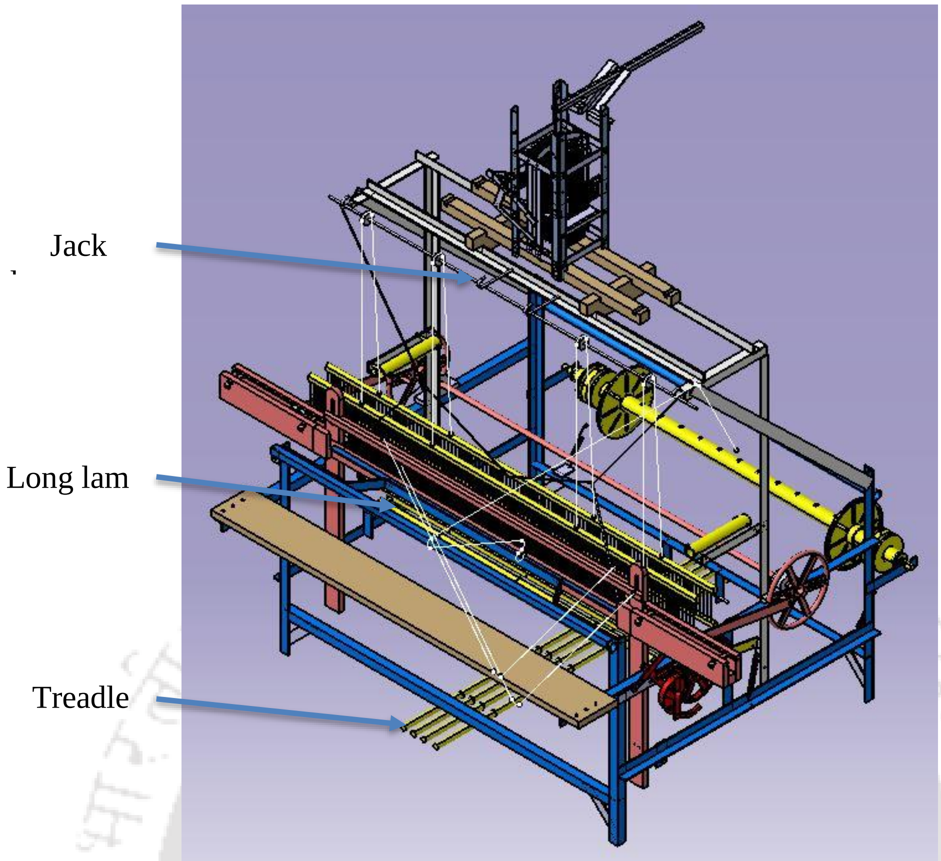


Figure 4.2: Isometric view of Shanti loom from front

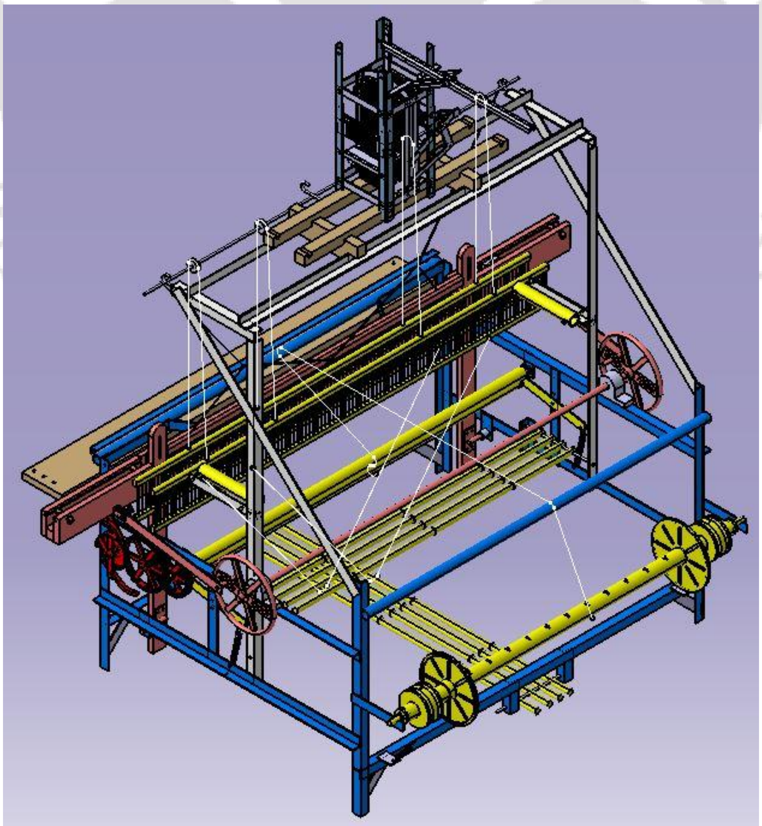


Figure 4.3: Isometric view of Shanti loom from back

The structure of the loom is made up of an L-channel. Many times these channels are hard to do machining. We need accurate marking to make holes; shifting position may cause misalignment and more rework time. CNC drilling is required for the proper position of the hole for proper fit between parts. The profile cutting takes more milling time, like the bracket used for warp beam mounting and knot profile in a round warp beam. These are some of the limitations of mass manufacturing of the structure.

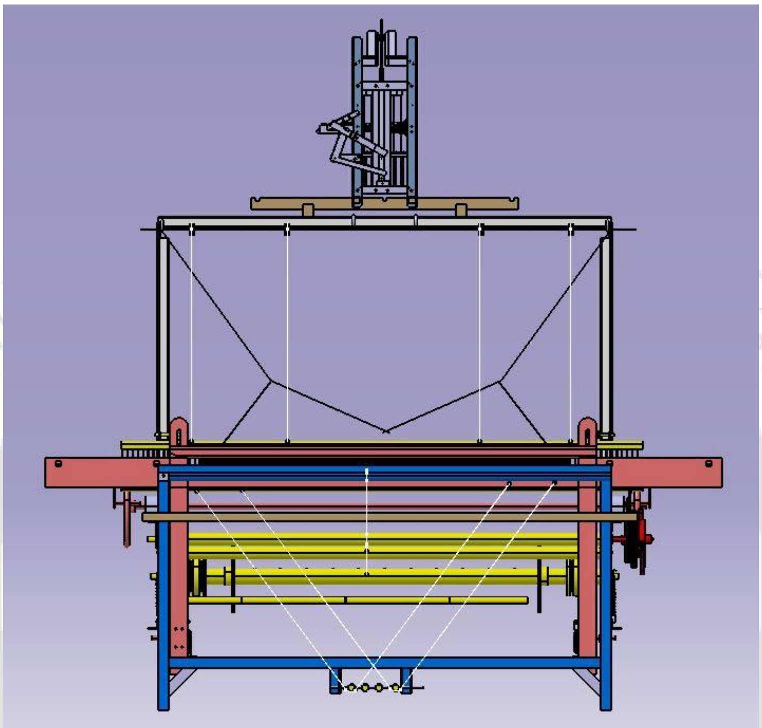


Figure 4.4: Front view of Shanti loom

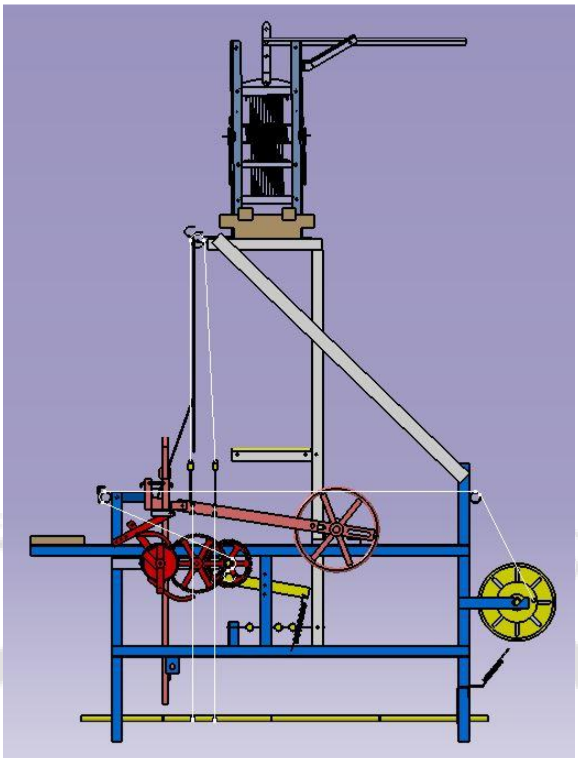


Figure 4.5: Right side view of Shanti loom

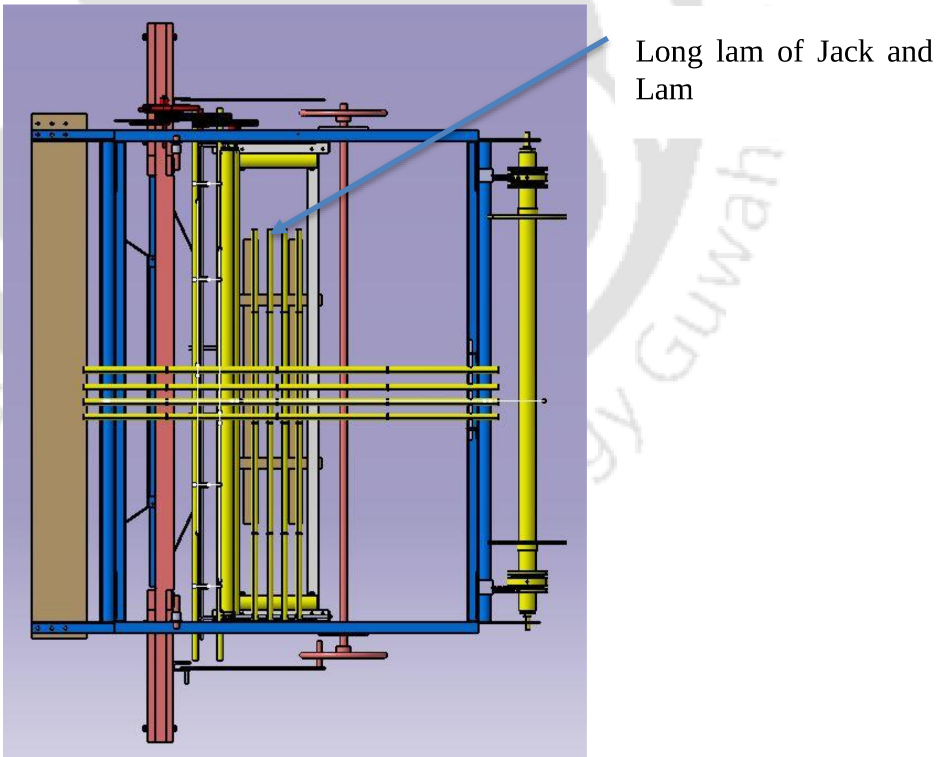


Figure 4.6: Top view of Shanti loom

Some of the critical sections of the Shanti loom have shown below like take-up mechanism shown in Figure 4.7 and 4.8.

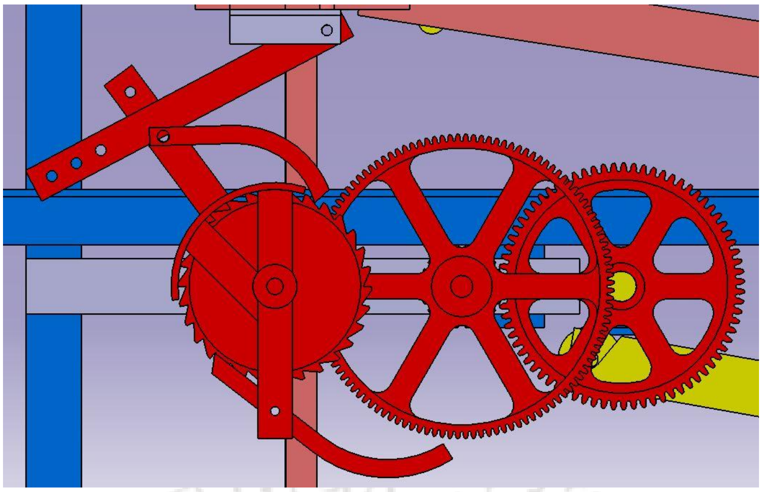


Figure 4.7: 5-Wheel gear mechanism front view of Shanti loom

Above 5-wheel gear mechanism consist of three shafts. Sometimes, the gears disengage due to the excess gap created between two gears. It is possible that due to the oversize of the hole in the fitting area, the lateral face is not perpendicular to the peripheral surface of the shaft, causing taper alignment. It can also occur due to extra torque generated during rotation to pull apart two gears forcefully.

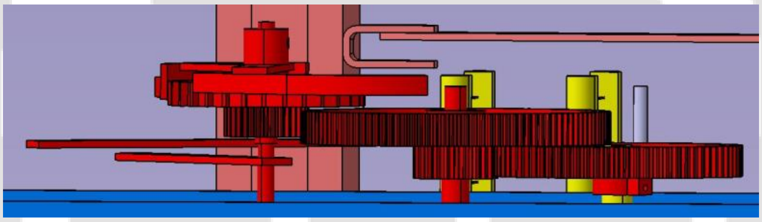


Figure 4.8: 5-Wheel gear mechanism top view of Shanti loom

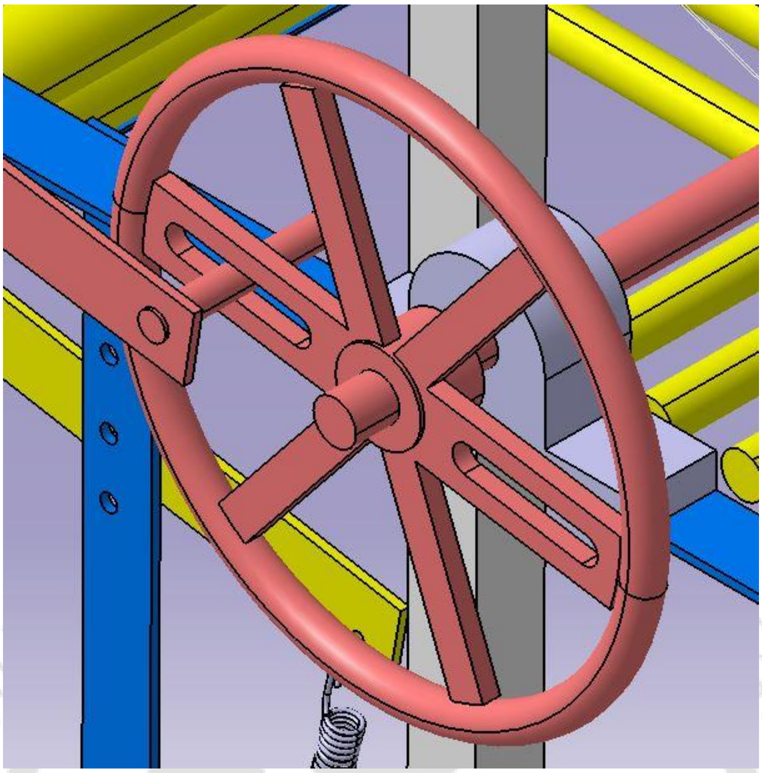


Figure 4.9: Fly wheel in Shanti loom

This flywheel worked with equal weight distribution throughout the periphery for smooth crank actuation as shown in Figure 4.9. It is made up of casting, which increases its cost and tooling cost. It also restricts working with limited vendors due to tooling expanse.

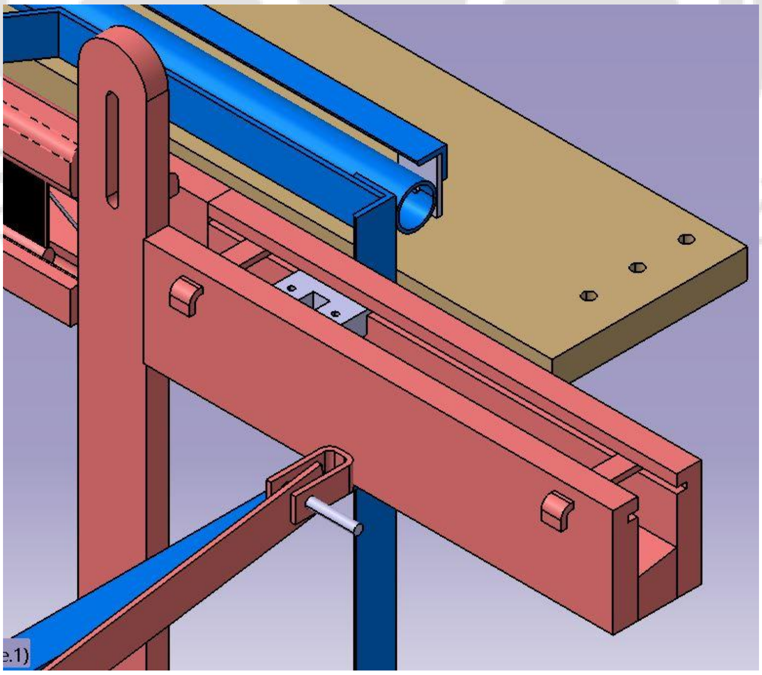


Figure 4.10: Wooden shuttle box in Shanti loom

Sley shown in Figure 4.10 was wooden with two leather strips working as a stopper for the picker. The wooden sley race has 5 degrees of inclination toward the reed so that shuttle will not fall midway between both shuttle boxes. The bench seating system had a 10-degree inclination towards the loom for weaving.

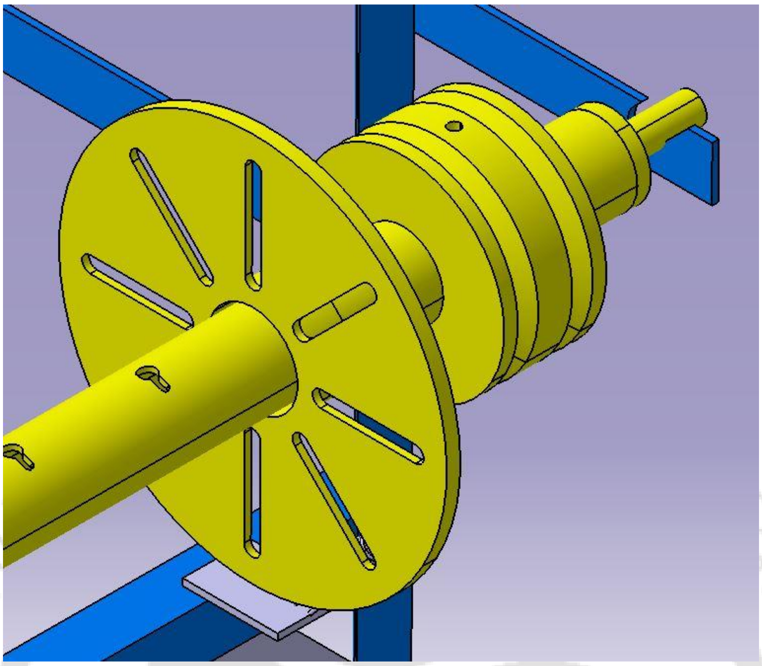


Figure 4.11: Warp flange in Shanti loom

Warp flange shown in Figure 4.11 was made up of a casting bracket with milling and drilling. It increases the manufacturing cost. The rope holder was made up of wood and needed some turning operation to make V-shape for rope support to execute the let-off operation in conjunction with take-up motion.

The physical model of the Shanti loom is shown below in Figure 4.12

Figure 4.12: Physical model of Shanti loom [15]

4.5.2 Prototype design and development

Conceptualization started with the Shanti loom, and an alternative to the traditional fly-shuttle loom was searched to increase the utility of the handloom by increasing its productivity and valuable life [15].

This research discusses the design process of a semi-automatic handloom by improving productivity and reducing manually operated motions of traditional handloom without affecting ornamentation capability. Handloom specialization is that it can be stopped and weaved as required for ornamentation design.

Shedding motion is operated manually by the lower limb with treadles. Picking is done by oscillating the sley using a Burmese type of cam synchronized with the beat-up motion of the sley. Take-up motion is made with 5-wheels take-up motions actuated by the oscillation of the sley sword and let-off through negative friction type assisted by take-up. Automatic roller temple motion is the withdrawal of woven cloth by take-up motion.

An alpha model is designed based on a modular knockdown type rectangular tubular section of the mild steel frame.

The treadle of the loom is similar to an automobile pedal to reduce effort during shedding.

Burmese type picking provides this facility to control the motion of the loom, and inertia of moving sley is used to propel the shuttle while reversing the sley. The new semi-automatic loom's conceptual design uses a Burmese-type picking mechanism, which synchronizes with beat-up motion. Sley movement will be manual with a unique handle ergonomically designed, which both left and right hands can operate. Handle fitted on the sley is the revolving type to facilitate knuckle movement during to & fro motion.

The loom is also fitted with a spring-loaded oscillating backrest and an adjustable weaver's seat to reduce strain.

An alpha model is designed to materialize the idea in physical form to ensure its function. All swing motions have been checked for clashes after 3D modeling the loom to avoid the major problem during manufacturing and trial. The design for assembly and manufacturing (DFA & DFM) methodology was followed for conceptualizing the design. Aesthetics and Human Factors were considered to enhance the perception of the loom and improve the work environment for the comfort of weavers.

An alpha model of the design for trial was fabricated to ensure technical feasibility. Motion-wise effects on function have been tested with this handloom. Few sub-systems inter-connected via mechanical links and gear mechanisms to eliminate manual intervention in the weaving cycle's picking, take-up, and let-off motion. This synchronization between sub-systems is better with steel structures than wood. The addition of partial automation in the handloom could reduce the weaver's drudgery without affecting the manual craft done by the weaver in the handloom product. Also, it could provide the weavers living a healthy lifestyle.

Steel-made loom will be costlier if it consists of more manufactured parts and costlier machining. The handloom design has been focused on an individual part level to use readymade parts and materials to reduce the overall cost of the handloom without affecting function.

It has been checked the feasibility of using steel over wood in handloom and the effects on various motions of handloom during operation in this research. Based on our product brief, it is found that solutions for all problems will be challenging to get through the existing wooden handloom. It is because of the unavailability of quality wood material for handloom fabrication, and there is a shortage of skilled carpenters for fabrication. Against this, metal fabricators are readily available cheaply in urban and rural areas. We can also protect the environment by avoiding wood material. Pine wood is used like sley race for shuttle movement, end support to the shuttle in the shuttle box.

Motion-wise effects on function have been tested with this handloom. Few sub-systems inter-connected via mechanical links and gear mechanisms to eliminate manual intervention in the weaving cycle's picking and let-off motion.

The alpha-model of the loom was fabricated with a Rectangular tubular mild steel section with 2mm thickness and found few difficulties in fabrication and machining. Extra care is required to fabricate and build this loom, like difficulty during welding due to less thickness of the tube, change in tube shape during tight clamp for cutting and machining, and drilling concentric holes. A Schematic Diagram of this alpha model concept is shown in the Figures 4.13 to 4.17.

New semi-automatic handlooms should be capable of high production, cost-effective, and easy to transport. Also, it should be weaver friendly and have a superior synchronization between the weaver, loom, and their environment. These requirements again push to improve the structure and manufacturing design along with easy assembly, disassembly, and maintenance. These are considered in the beta model of the semi-automatic handloom.

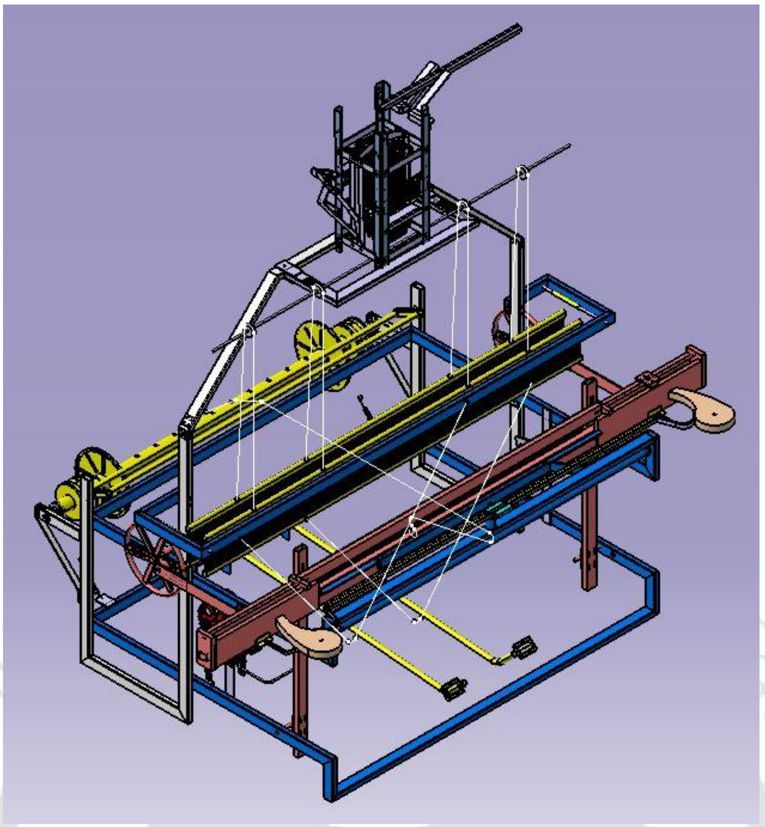


Figure 4.13: Isometric view of alpha model of semi-automatic handloom from front

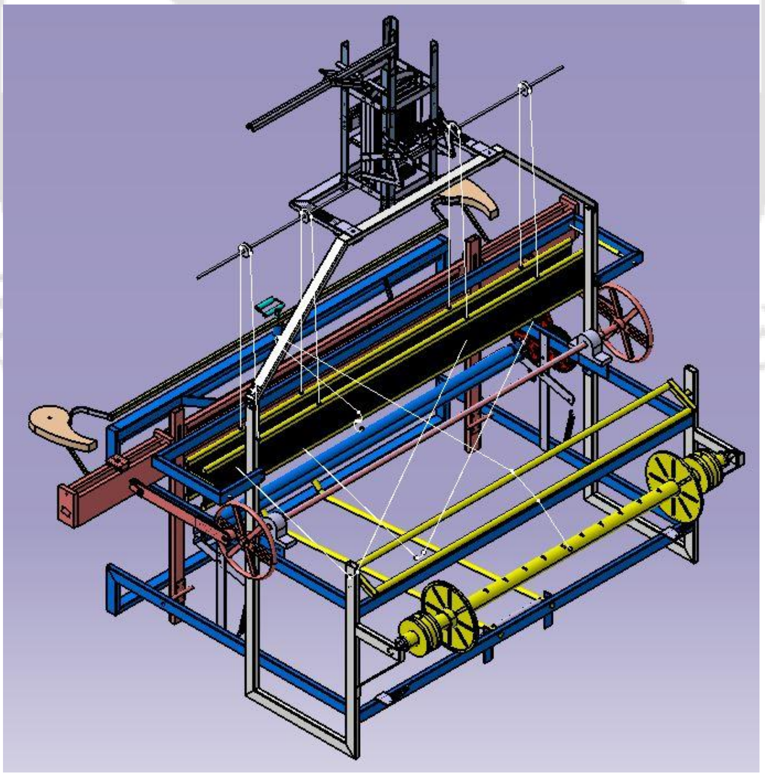


Figure 4.14: Isometric view of the alpha model of semi-automatic handloom from back

In this model rectangular tubular section of mild steel structure is used in place of the L-channel in the Shanti loom. A mild steel tube is difficult to provide form for aesthetics or function in a rectangular tubular section. Also, this is not easy to machine like milling, drilling etc. Milling has heavy chatter sound and non-concentric hole possibility during drilling etc. are a few issues to provide designed shape. The remaining material is also used locally or as existing materials in the institute workshop. Many parts are taken from the Shanti loom to check the function of the new mechanism.

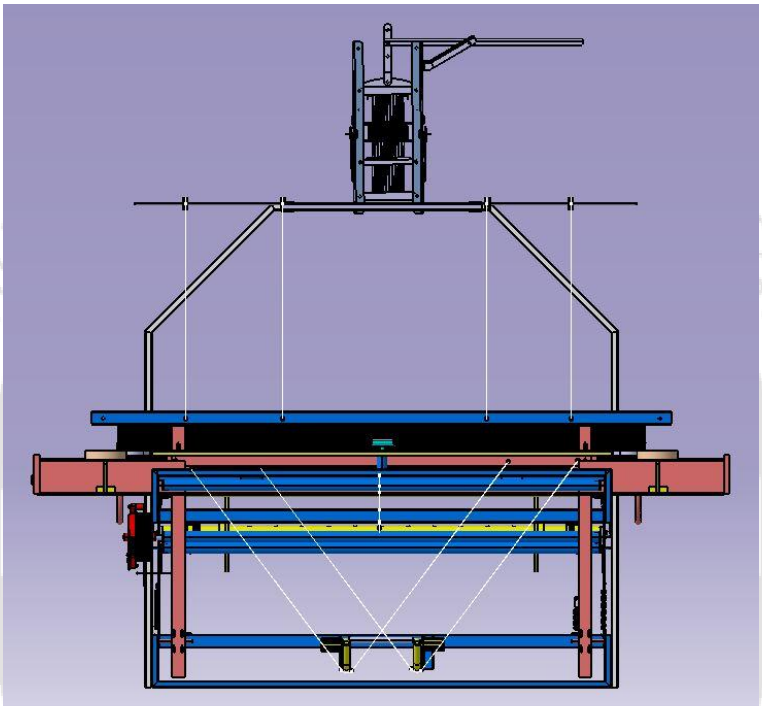


Figure 4.15: Front view of alpha model of semi-automatic handloom

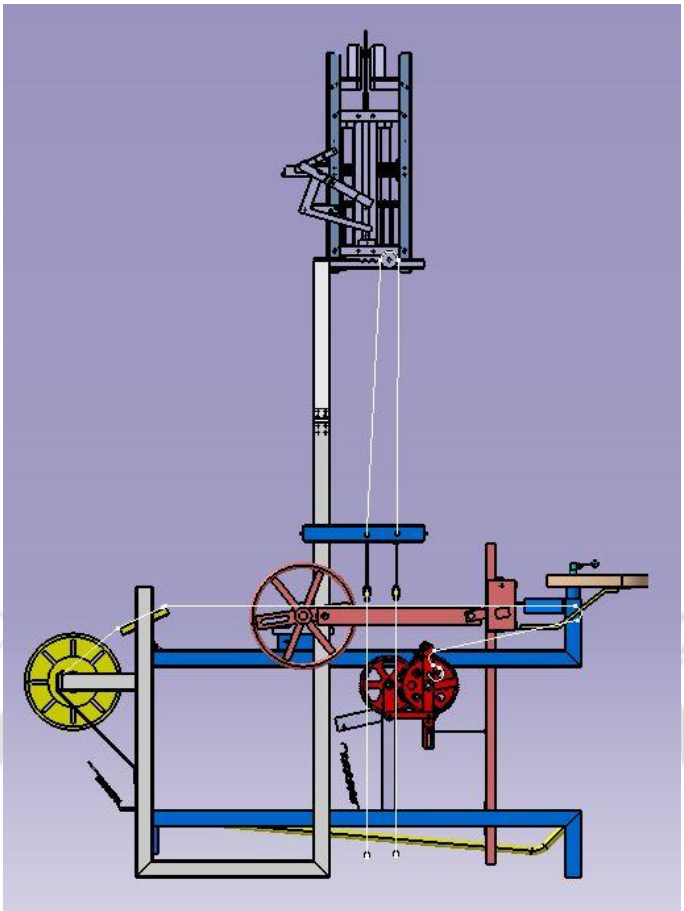


Figure 4.16: Left side view of alpha model of semi-automatic handloom

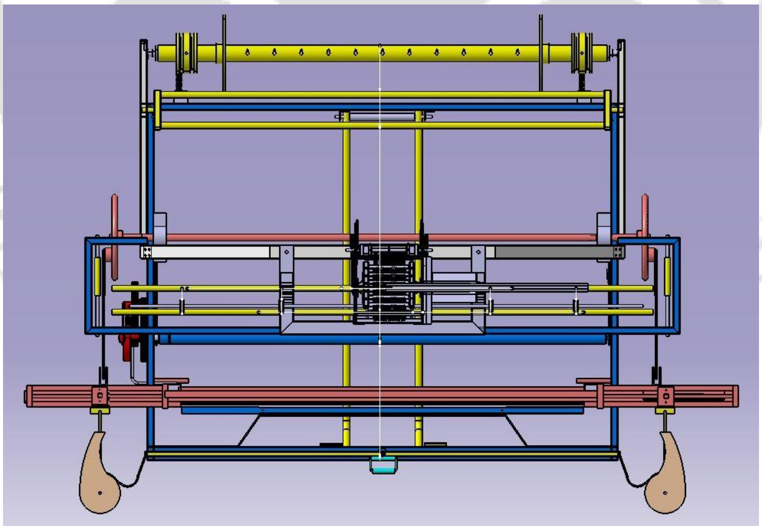


Figure 4.17: Top view of the alpha model of semi-automatic handloom

This Fly shuttle semi-automatic loom incorporates manually operated independent shedding motion. If automatic shedding is incorporated, the loom becomes more complex to operate, and the flexibility of ornamentation is lost. Therefore, this was not considered. In the Alpha model, shedding requires engaging both the feet and facilitates mending the broken ends.

Next to the treadle are provided two footsteps (similar to that in automobile) where the weaver can rest her feet when they do not weave and mend broken ends.

Treadles are designed in the round tube, but a square section would have been a better alternative. The design of the treadle, as shown in Figure 4.18, is to operate like an automobile's foot pedal with a comfortable seat.

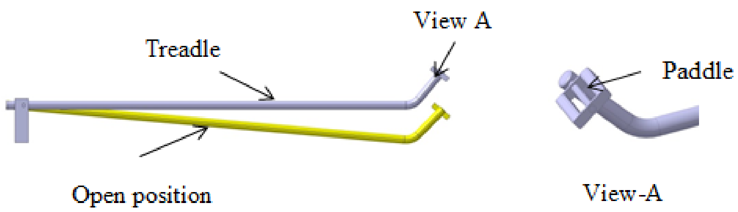


Figure 4.18: Conceptual design for a treadle in the semi-automatic handloom

Creating holes in the round tube for pivot and paddle is difficult to drill relatively compared to square tube.

Picking motion

The Burmese type picking mechanism works in conjunction with the beat-up mechanism. When the sley is taken to the extreme rear position, the shuttle is automatically propelled through the shed over the race board from one shuttle box to the other.

The synchronization required for this is that the weaver needs to form the shed by depressing the treadle as per the weaving pattern.

Material of sley race is kept as wood as it gives smooth movement compared to steel. Also, manufacturing of sley race is easy with wood compared to steel. Alternative materials will be explored in the upcoming concept to achieve the best functional results with aluminum and composite material.

Synchronization between picking and beat-up works smoothly due to the crank mechanism fitted with the shaft that controls the sweep of the sley. The above synchronization achieves by the rotational movement of the main shaft.

It took various alternatives to try when the shuttle was frequently falling. We have checked the warp line thoroughly to position the surface of the sley race. Also, it has been level with the help of spirit level. Rope length variations with the smooth shuttle flow in the shuttle box without much resistance were adjusted to get the correct combination. Shuttle movement has been tested with a leaf spring, as in Figures 4.19 to 4.22, on one side of the shuttle box to put auxiliary pressure along with a picker to push the shuttle.

Figure 4.19: Leaf spring used in the shuttle box

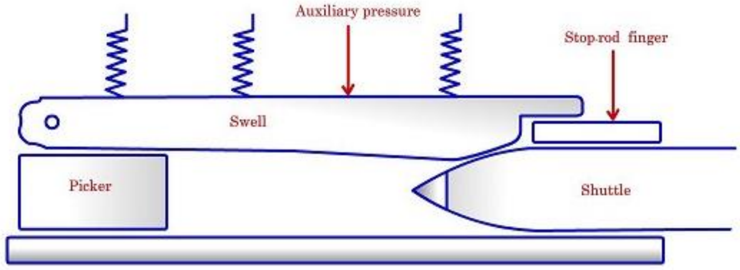


Figure 4.20: Spring-action used to propel the shuttle from the shuttle box

Figure 4.21: Right side Shuttle box with spring action

Figure 4.22: Left side Shuttle box with spring action

Take up and Let off motion

The take-up works in conjunction with the sley sword's reciprocating motion. When the sley comes forward, the pick-up ratchet slides over the take-up guard and, in the reversing motion, pulls forward the ratchet wheel as per the setting of the pick spacing. Also, the take-up mechanism is modified to house all the five gear wheels on only two shafts. The ratchet wheel, compounded change wheel, and take-up guard are freely mounted on the emery roller shaft. The change wheel drives the stud wheel, which is compounded with stud pinion and mounted freely on the stud pin. The stud pinion drives the emery roller wheel fixed onto the emery roller shaft. Adjustment of pick spacing is possible through the lever mounted on the stud pin and secured to it with nuts and bolts. It holds the take-up guard in a fixed position.

Let off mechanism works in conjunction with the take-up mechanism. The positive take-up of the woven materials generates tension on the warp sheet, and when this tension exceeds the resistance provided by the spring-loaded let-off mechanism, it lets off the required amount of warp.

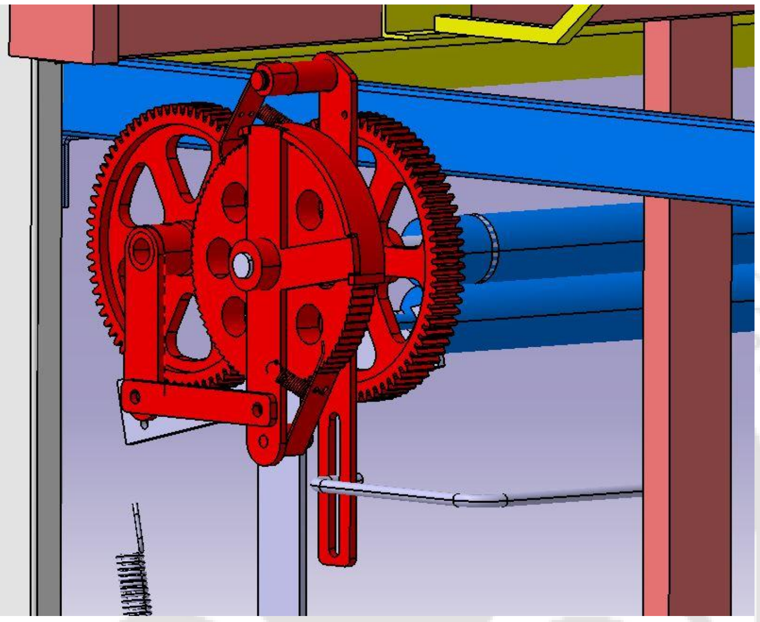


Figure 4.23: 5-Wheel gear mechanism of the alpha model of semi-automatic handloom

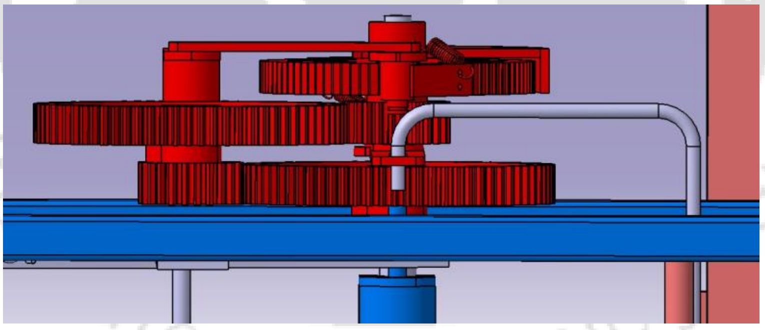


Figure 4.24: 5-Wheel gear mechanism top view of the alpha model of semi-automatic handloom

5-wheel gear mechanism of take-up motion is shown in Figure 4.23 and 4.24 with new compact orientation. Foot paddle shown in Figure 4.25 is lifted up to avoid rubbing during shedding operation.

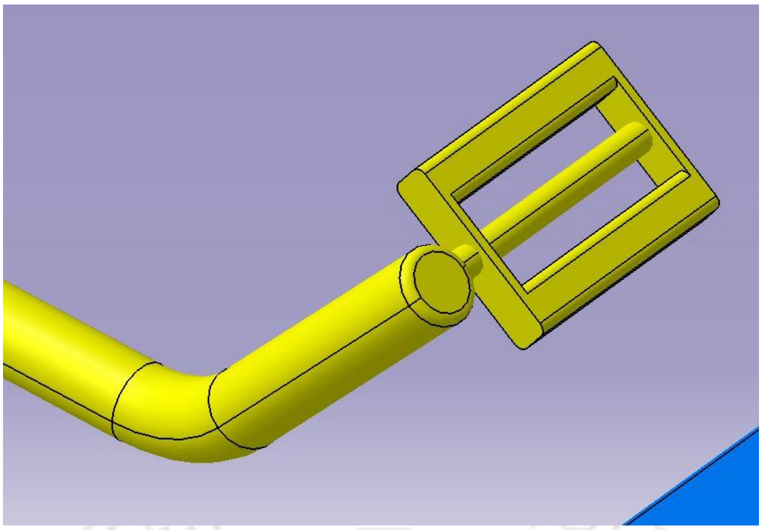


Figure 4.25: Treadle with foot paddle in the alpha model of semi-automatic handloom

The open shed is used for shedding motion. The semi-open shed is used during using jacquard for ornamentation

Beat up motion

Sley movement for beat-up will be manual with a unique handle ergonomically designed and operated by both left and right hands. This newly designed handle will give additional comfort to the hand aligned to the wrist of the weavers, as shown in Figure 4.26 to 4.29. Wrist comfort is provided in a beat-up handle through slight movement on two required degrees of freedom.

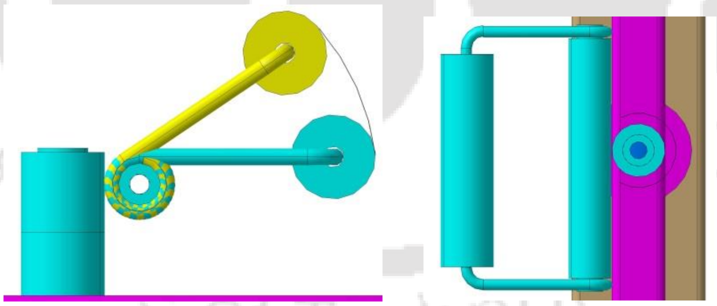


Figure 4.26: Conceptual design of a handle for beat-up motion with rotational freedom aligned to the wrist and hand adjustment of the weaver

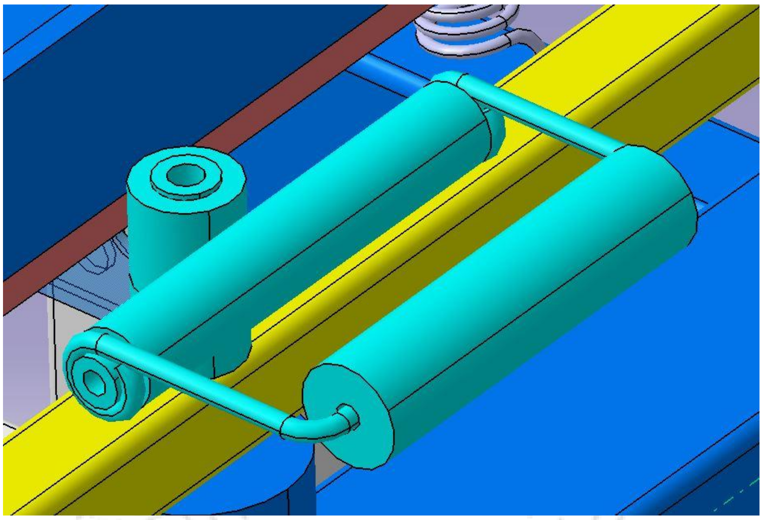


Figure 4.27: Handle for beat-up in the alpha model of semi-automatic handloom

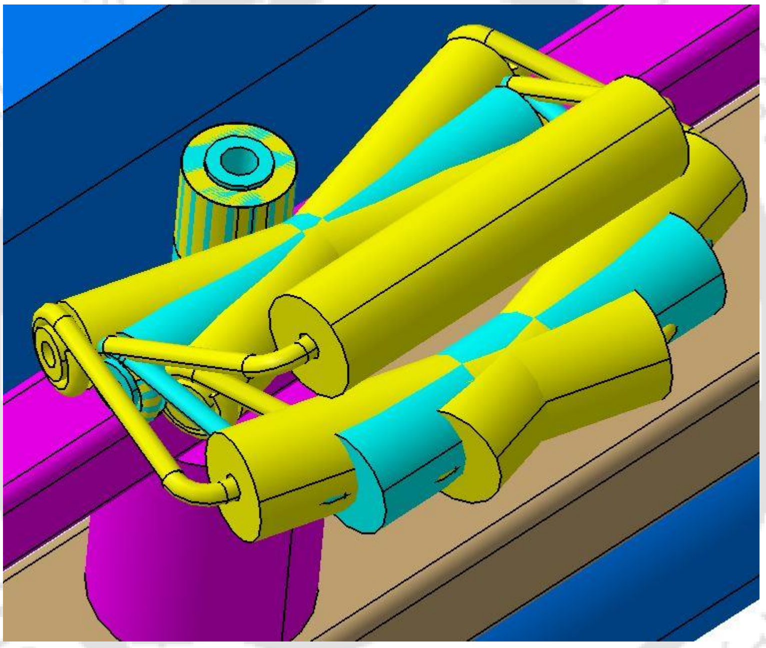


Figure 4.28: Handle open position for beat up in the alpha model of semi-automatic handloom

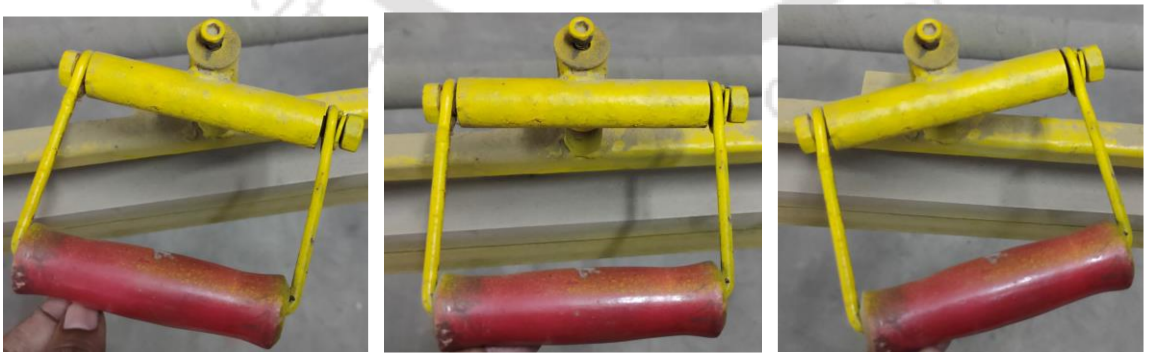


Figure 4.29 Beat-up handle with its open position

A flange shown in Figure 4.30 is used to keep the warp in fixed width

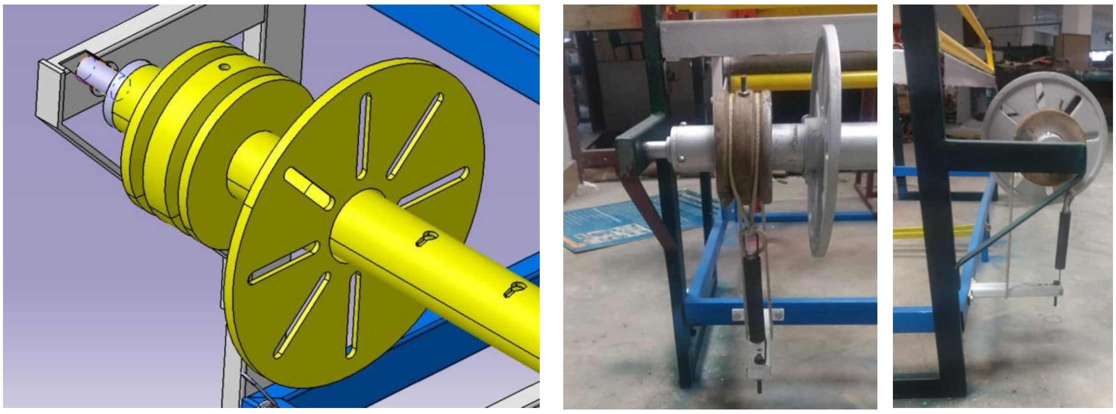


Figure 4.30: Warp flange and spring with warp beam in the alpha model of semi-automatic handloom

Temple motion

The temple mechanism also works when the woven cloth is taken up. The rollers inside the temple mechanism allow the cloth to come forward for rolling onto the cloth roller.

Figure 4.31: Traditional temple motion

Traditionally temples are made up of a flat wooden piece with a nail attached to it as shown in Figure 4.31. It does not allow the fabric width to become narrow. Roller temple shown in Figure 4.32 and 4.33 control the fabric width from outside.

Figure 4.32: Temple mounting frame

Figure 4.33: Temple mounting with right side spring roller temple in Semi-automatic handloom

Oscillating back rest

The oscillating back rest shown in Figure 4.34 and 4.35 is loaded with spring to keep the warp sheet in uniform tension during shed formation. It only allows yielding the let-off mechanism after it has reached its limit and immediately takes up any slackness resulting from shed closing.

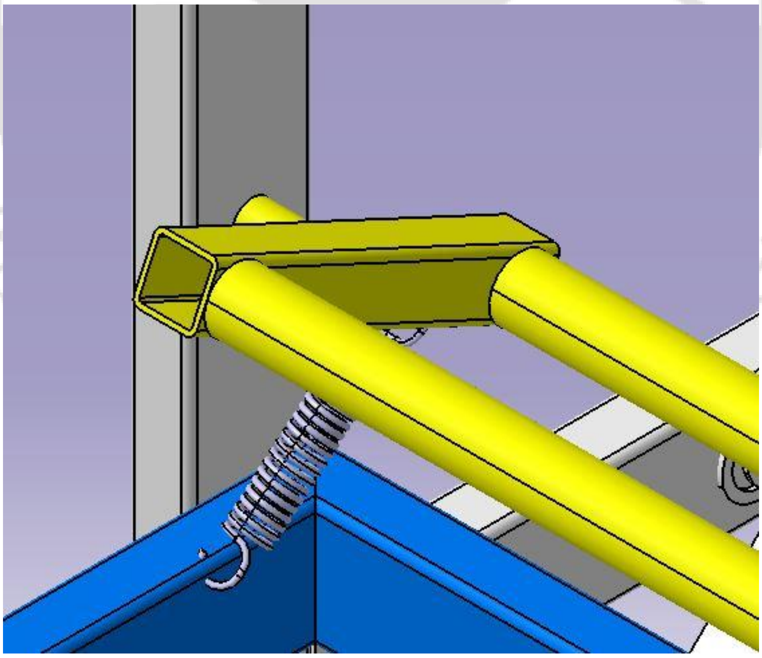


Figure 4.34: Oscillating backrest of the alpha model of semi-automatic handloom

Figure 4.35: Oscillating backrest with the round tube of the alpha model of semi-automatic handloom

Figure 4.36: Beam end

Cloth beam, emery roller beam, and front beam were prototypes through pipe and pivot pin fitted and welded at both ends. Initially, pivot pins were fitted and welded without a collar inside the center pipe of the beam. The idea is to fit both the part, i.e., pipe and 'pivot pin with plain washer (without collar)' as shown in Figure 4.36, through tack weld after clamping by two C-clamps. It was found that the pivot pin deformed after welding and not found concentricity required.

The pivot pin is attached to the stepped washer or washer with a collar of 5mm shown in Figure 4.37, which will insert inside the pipe to avoid deformation of the pivot pin from its center. As the pipe's internal diameter is not boring surface, a concentricity defect still exists in the beam.

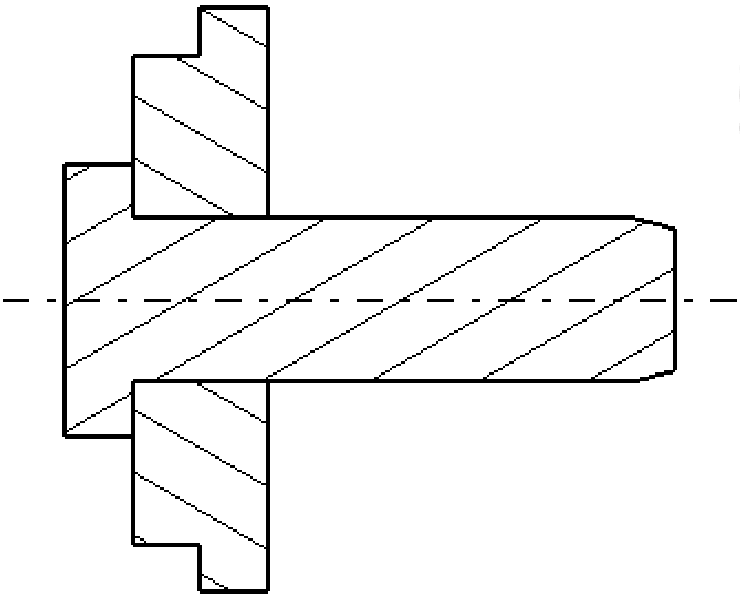


Figure 4.37: End cover with 5mm collar

4.5.3 Manufacturing of Alpha-model

The structure of the alpha model is made up of a rectangular tubular section of mild steel due to easy availability in the workshop and market. Cutting tubes was done by chop saw machine as shown in Figure 4.38 to cut straight or at an angle for joining with other parts. Example of angle cut part is shown in Figure 4.39 and example of welded product after cutting have been shown in Figure 4.40.

Figure 4.38: Chop saw machine[34]

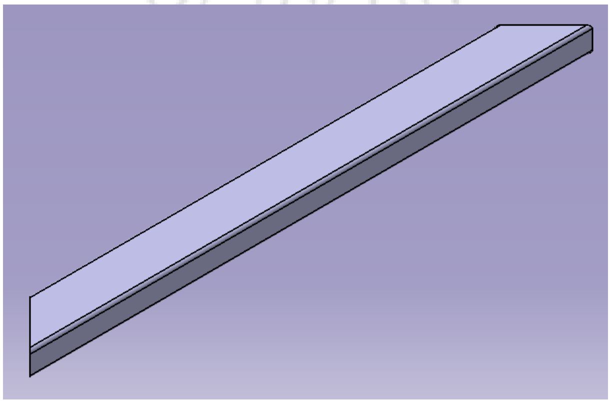


Figure 4.39: Angle cut parts

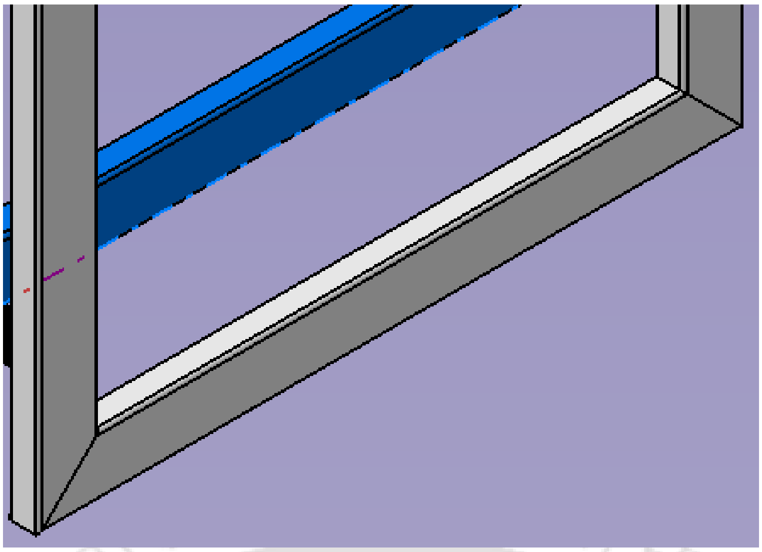


Figure 4.40: Welded products in the alpha model of semi-automatic handloom

The same cutting operation can also be done in a power saw machine as shown in Figure 4.41 and hand hacksaw shown in Figure 4.42.

Figure 4.41: Power saw machine [107]

Figure 4.42: Hand saw machine [108]

The next operation to make a handloom structure is joining through welding with other parts. In the local market, arc welding is majorly available. Arc welding machine shown in Figure 4.43 can burn out thin sheet causing weak structure.

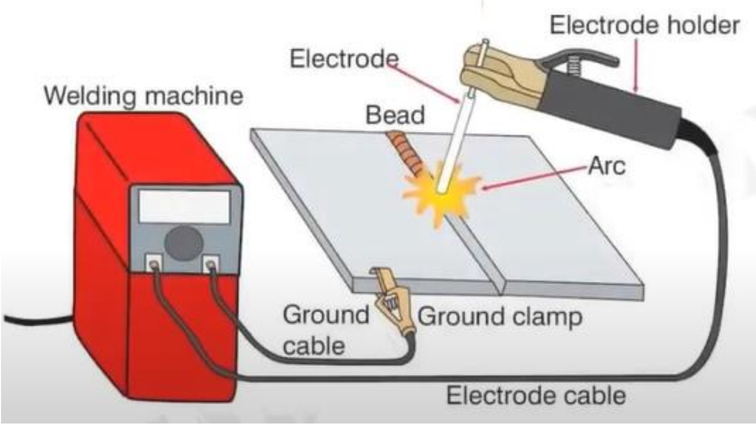


Figure 4.43: Arc welding machine [109]

MIG or TIG welding is suitable for welding thin sections. MIG welding is faster than TIG welding. MIG welding can weld above 1mm sheet thickness of steel, whereas TIG welding can weld even lower thickness.

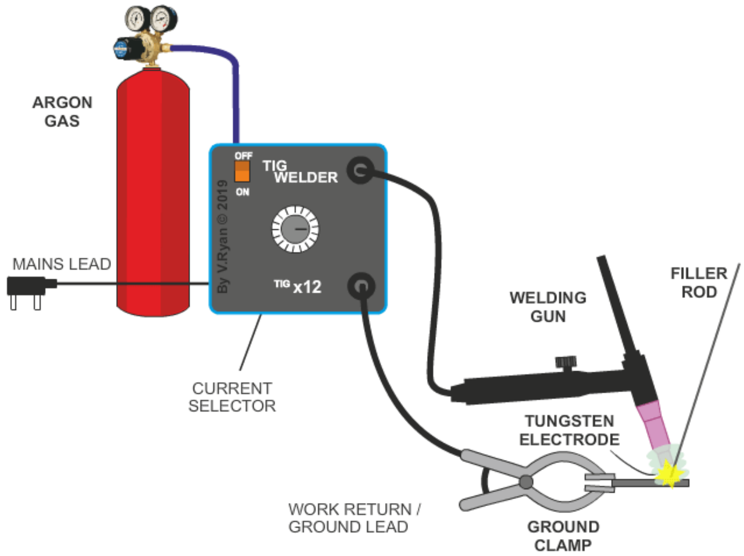


Figure 4.44: TIG welding machine [110]

TIG welding as shown in Figure 4.44 has a fixed tungsten electrode and hand-held welding rod to weld, whereas MIG welding has a machine-fed wire rod as shown in Figure 4.45.

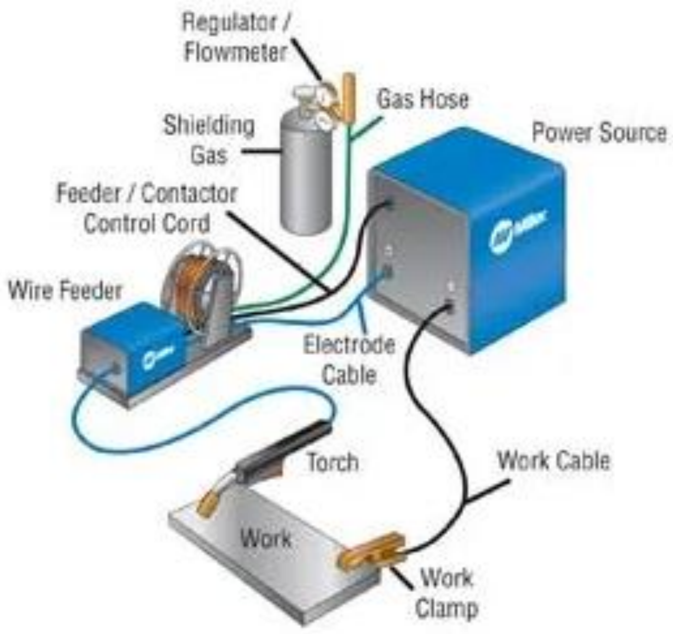


Figure 4.45: MIG welding machine [111]

Many parts also need a milling machine for slot machining or a drilling machine for making holes, as shown in the Figure 4.46 with a section of the alpha model of a semi-automatic handloom.

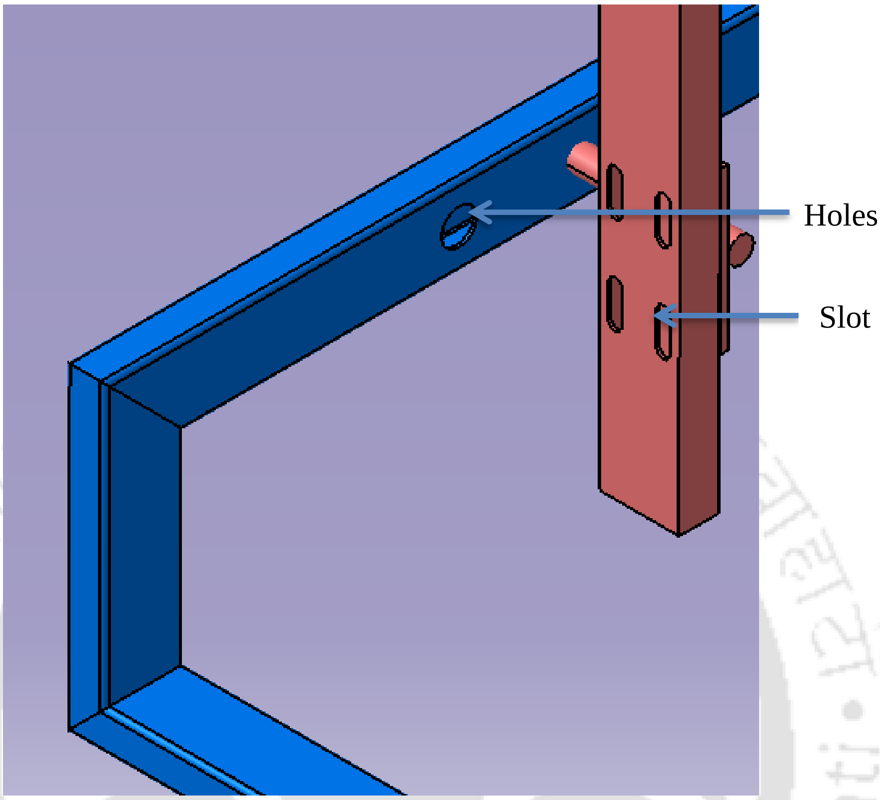


Figure 4.46: Parts and products with slots and holes

Making drills and slots in rectangular tubular steel section structure might be inaccurate due to no bottom support/clamp on the other side of the sheet. Holes or slots may not be concentric due to deflection of the tool once it crosses the top side sheet to the bottom sheet of the tubular structure. The position of holes and slots also might differ from the design, causing more rework during assembly in case of manual marking. CNC milling or drilling can be done to avoid manual marking for drilling/milling. Manual milling machine is shown in Figure 4.47 and manual drilling machine is shown in Figure 4.48.

Figure 4.47: Milling machine [112]

Figure 4.48: Drilling machine [113]

The rectangular tubular structure has a joining; due to that, there is a projection inside the tube. Drilling and milling are critical to machining on such projection as it is hardened with their neighboring area.

There are a few round parts manufactured through a turning/lathe machine as shown in Figure 4.49. There are minor works of milling, drilling, reaming, and tapping on those round parts. Casted Gears are used for take-up motion. Sley race with shuttle boxes is made of pine wood during the alpha model of the semi-automatic handloom. Carpenter makes wooden parts at the local level, experienced in making wooden handloom. Other than these manufactured parts, there are a few bought-out / readymade items like a picker, reed, heald, bright bar, pulley, spring, ribbon, and ropes.

Figure 4.49: Turning / Lathe machine

Assembly is done through nuts and bolts. Warp alignment through the loom from warp beam to cloth beam, the parallelism between warp beam, front beam, and cloth beam with emery roller was taken care of during assembly. Sley pivot at bottom and rod to rotate flywheel should also be parallel and with other beams for uniform beat up and feeding of warp from warp beam through take-up motion in synchronization with let-off motion.

Alpha-model was made purely using majorly readymade workshop facilities.

The physical alpha model is shown in Figures 4.50 and 4.51.

Figure 4.50 Manufactured alpha model of semi-automatic handloom

Figure 4.51: Manufactured alpha model of semi-automatic handloom 2

Picker to cam connected through a rope and cam to swing bracket connected through a ribbon as shown in Figure 4.52.

Figure 4.52: CAM to picker connection in the alpha model of semi-automatic handloom

Figure 4.53: Existing Gear mechanisms for take-up motion

Figure 4.54: Re-organisation concept of the 5-wheel gear train with two shafts for take-up and let-off motions

Figure 4.55: Compound gear of 5-wheel gear in the alpha model of semi-automatic handloom

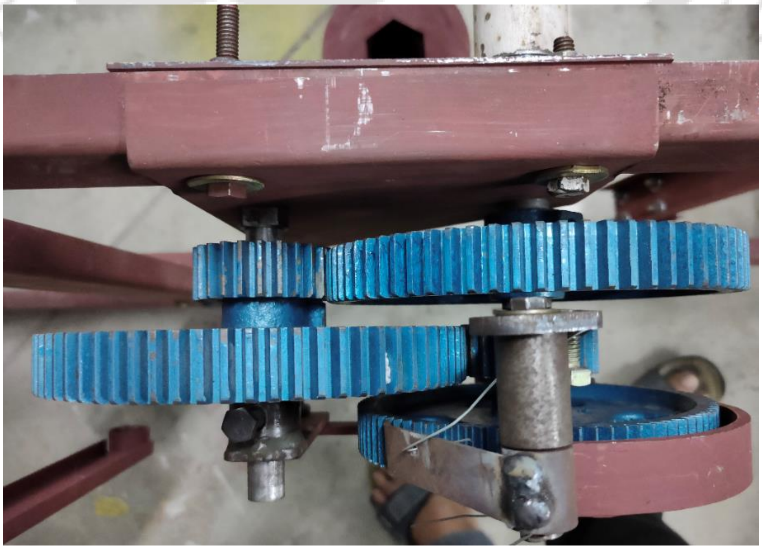


Figure 4.56: Top view of 5-wheel gear mechanism in the alpha model of semi-automatic handloom

Figure 4.57: Wooden temple motion in the alpha model of semi-automatic handloom

4.5.4 Design of Beta model of the loom

Redesign and refinement in design have been planned based on the trial run of the preceding two concepts to improve the final concept following PDCA (Plan, do, check, and act) cycle. After developing the alpha model, it was ensured that automatic picking, take-up, and let-off motion function as intended. In the beta model, developing the structure through sheet metal forming design was unique for various sub-system levels along with the seating system for proper function without much vibration during operation. Complete product details are shown below in Figure 4.58 to 4.62.

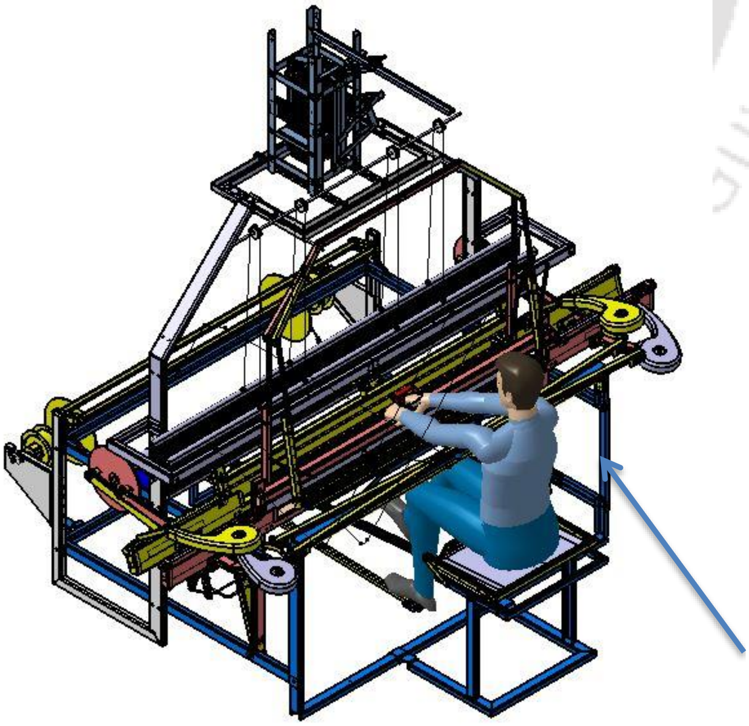


Figure 4.58: Isometric view of De-sign semi-automatic handloom from front

In the alpha model, there was no reinforcement between the upper and lower frame on the front side as the upper frame was hanging like a cantilever, and the side frame supported the backside. One reinforcement has been added to control vibration in the sheet metal structure of the beta model.

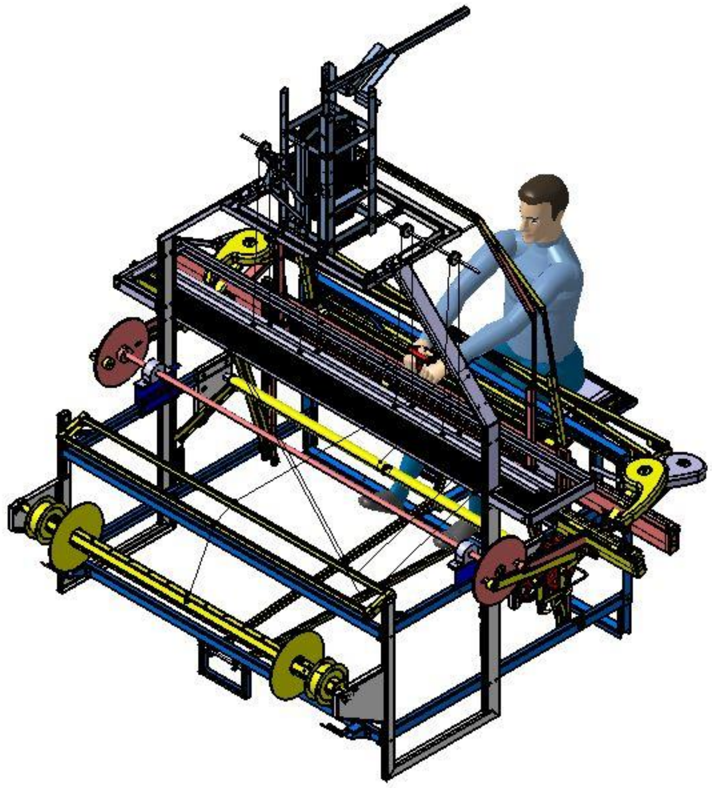


Figure 4.59: Isometric view of De-sign semi-automatic handloom from back

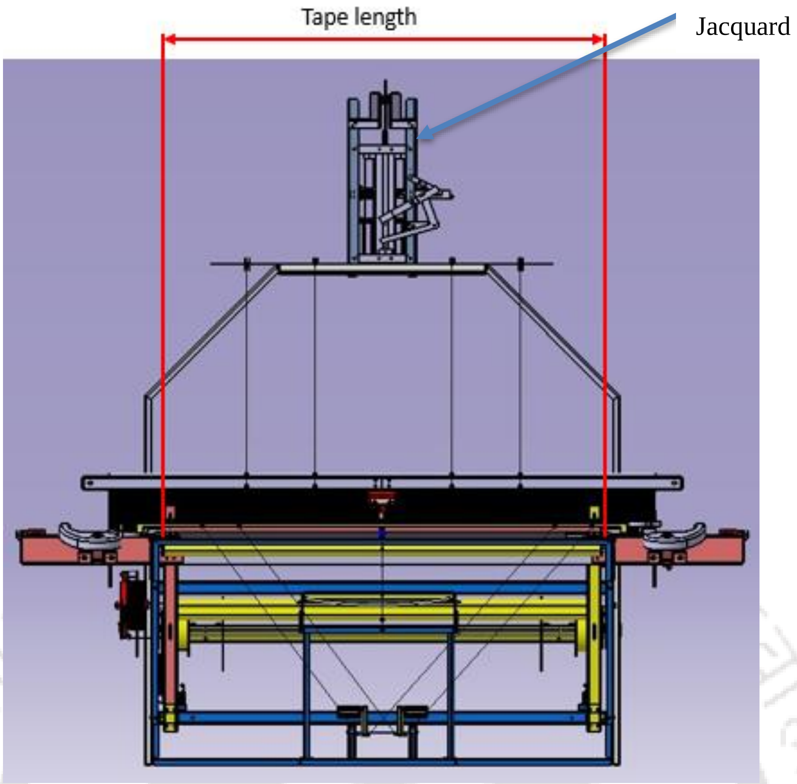


Figure 4.60: Front view of De-sign semi-automatic handloom

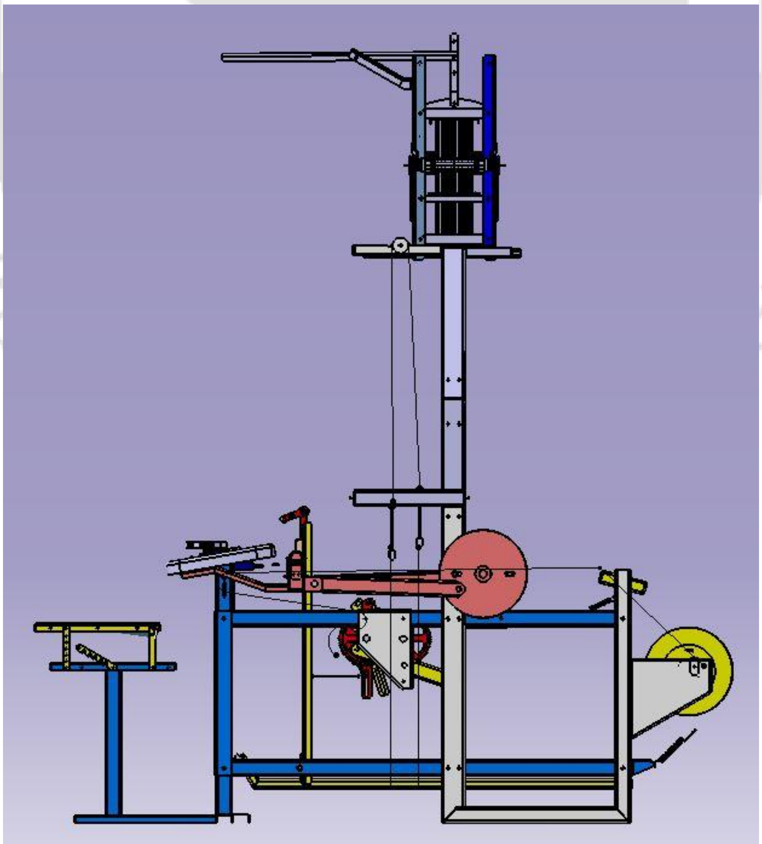


Figure 4.61: Right side view of De-sign semi-automatic handloom

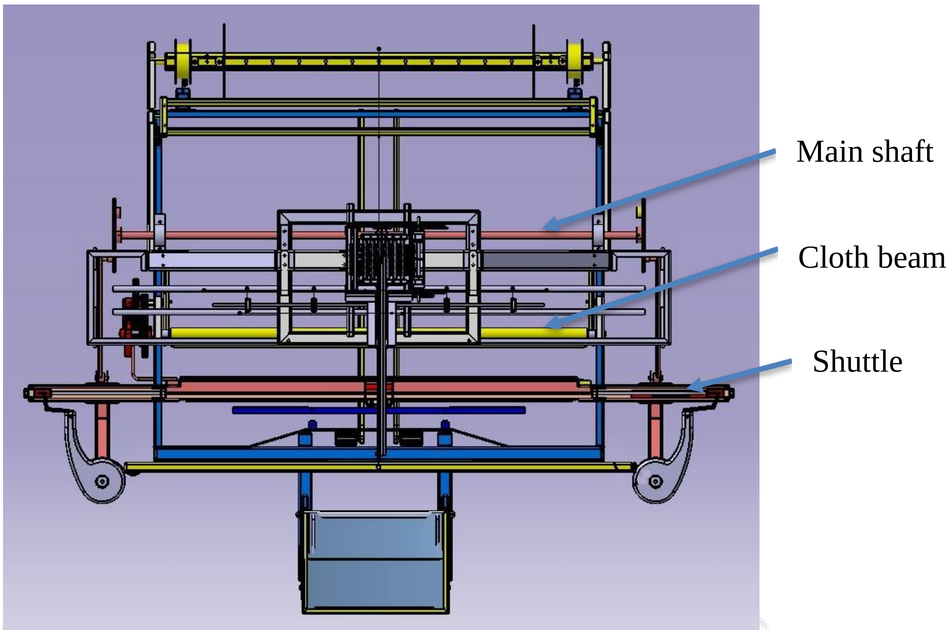


Figure 4.62: Top view of De-sign semi-automatic handloom

The structure of the handloom has been designed by keeping the nut inside the tube, as shown in Figure 4.63. It is made to avoid outside projection of the nut and projected threaded portion of the bolt.

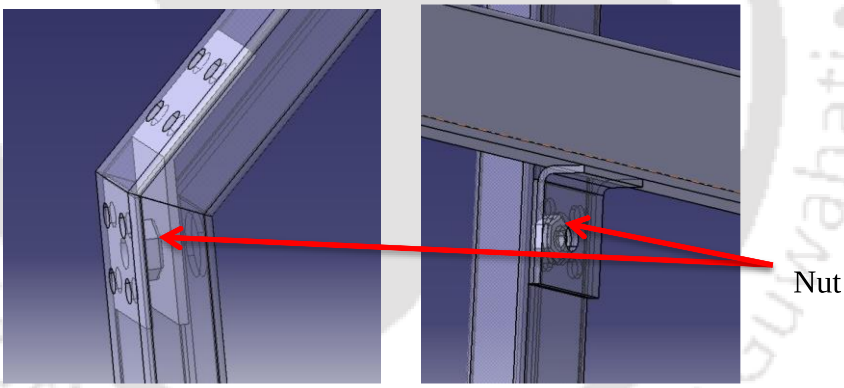


Figure 4.63: Structure with a nut welded inside

Also, round holes and slotted holes are used in two mating parts as shown in Figure 4.64 considering diamond pin design in fixture design for location and easy fitment between two mating parts. It reduces the rework time during assembly.

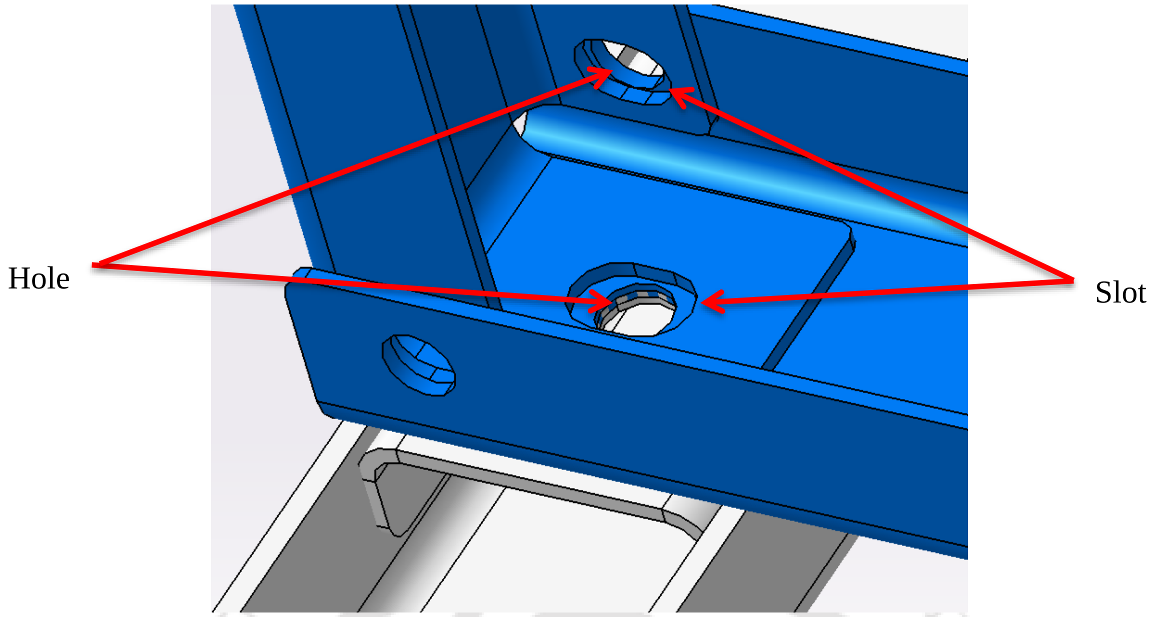


Figure 4.64: Round and slotted holes in the structure of a semi-automatic handloom

Bearings are used in rotational points like sley pivot, cam pivot, and ‘crank of sley to flywheel’ to reduce friction and increase weaving speed.

Treadle design

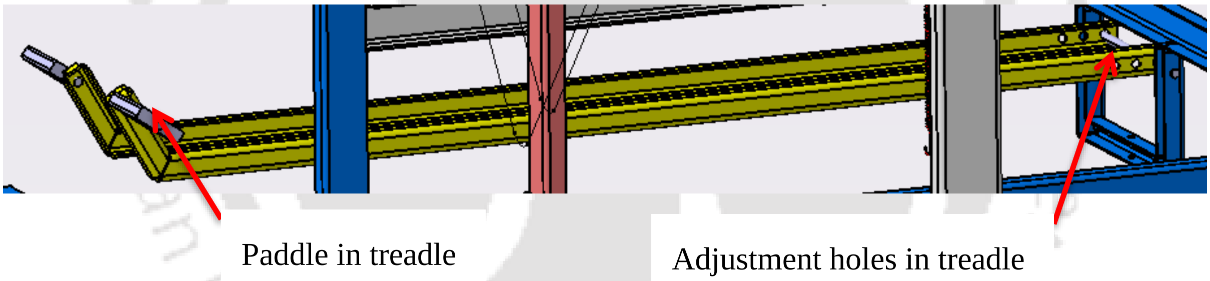


Figure 4.65: Treadle with adjustment

The treadle must be strong as it overhangs too long from extreme back to front. A Square of 20mm or 1 inch is a good choice for a treadle. Sheet metal treadle will work with a helpful guide to keep the treadles apart from each other on the front side of the handloom. The guide will restrict from twisting of sheet metal treadles. Treadle also have adjustment as shown in Figure 4.65 as a secondary adjustment for ergonomic requirement.

The frame should have enough clearance to pass through the warp yarns between the front beam and front bar of the top frame without obstacle as shown in Figure 4.66.

Figure 4.66: Fall entry clearance in front beam and structure of semi-automatic handloom

Initially, the whole structure was designed through 2mm thickness, considering the uniformity among all the parts and referring size of rectangular tubular section used in alpha model. During the trial, few parts could not bear the force exerted during the weaving operation. Therefore, some parts were modified to 3mm from 2mm thickness to check the performance. Also, it requires resizing and adding reinforcement in some parts/sub-systems. Below shown parts in Figure 4.67 are modified into 3mm in the beta model like treadle, Front top frame for cam actuator bracket, Side frame, Jacquard mounting/pulley holder for shedding, Warp support in warp beam, Cam holding bracket, Reinforcement of cam holding bracket, in bend area, Sley race mounting bracket LH/RH. Few links are used in the 5-wheel gear mechanism; the seating system is made up of 5mm thickness.

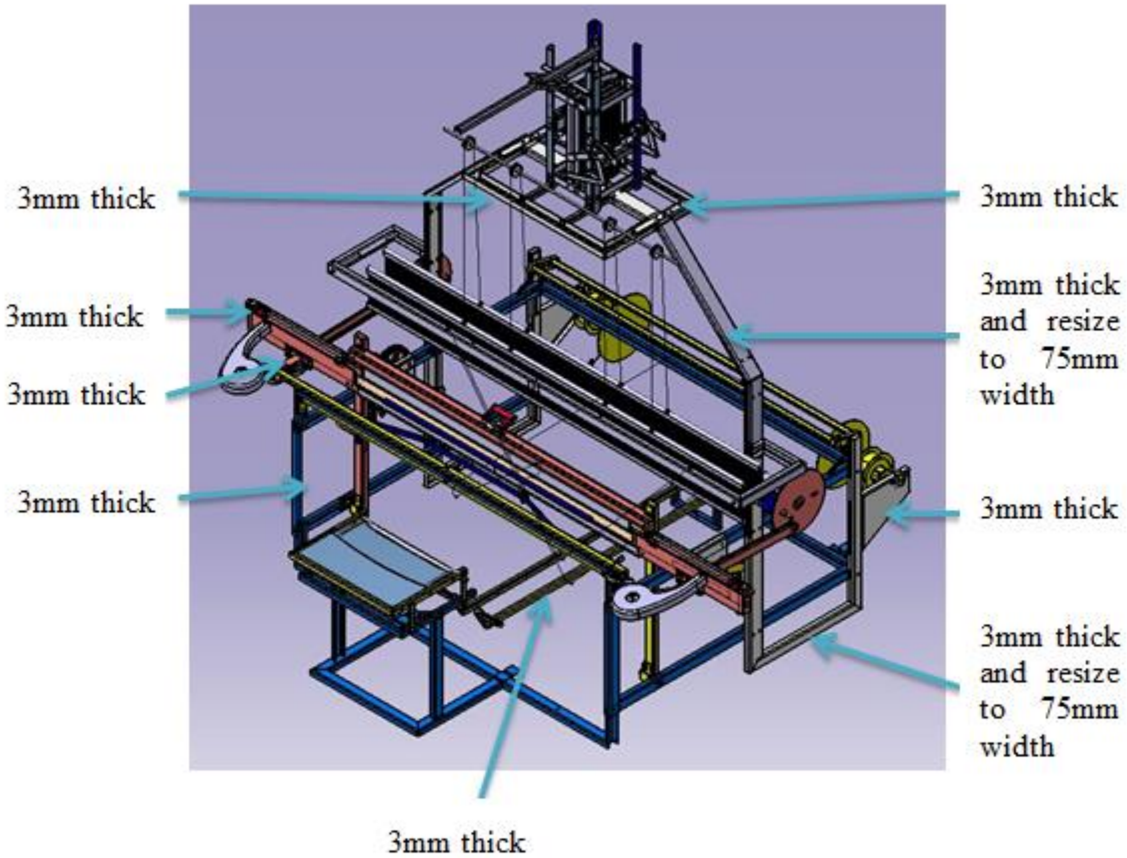


Figure 4.67: 3mm sheet thickness parts to avoid vibration of De-sign semi-automatic handloom

The treadle was initially made up of 2mm twisting in the paddle side due to clearance between the treadle bracket and pivot pin in the lower frame backside. Later it is made with 3mm thickness, which is working well.

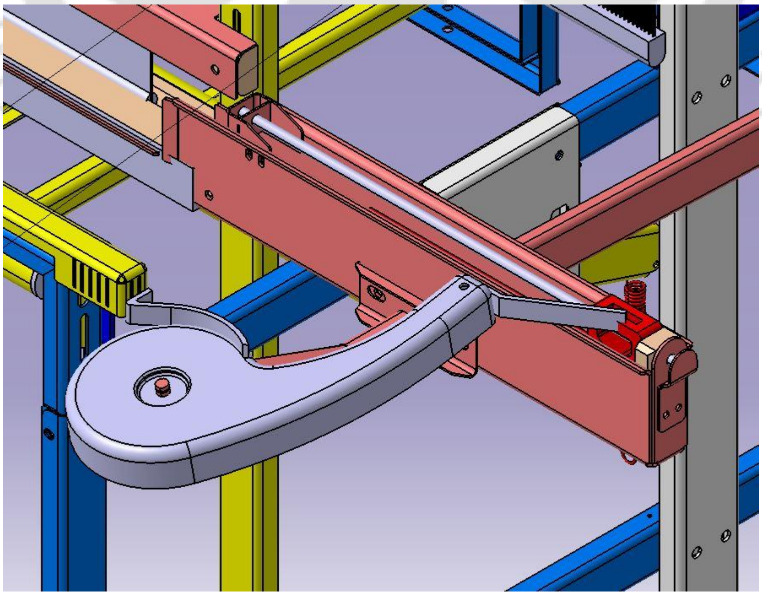


Figure 4.68: Burmese type of picking mechanism of De-sign semi-automatic handloom

Figure 4.69: CAM on process

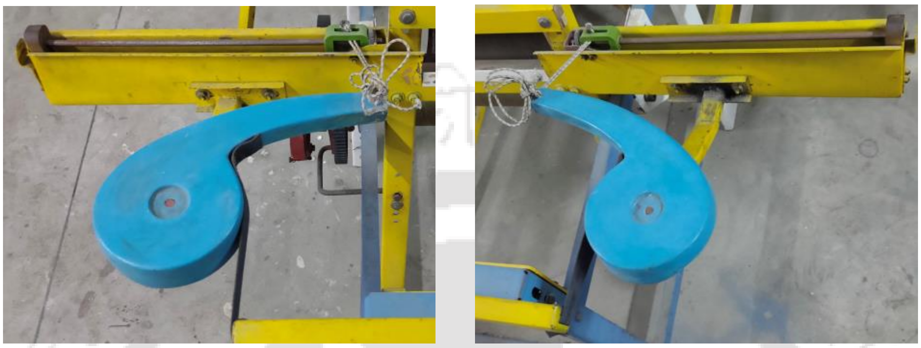


Figure 4.70: Picking Cam with ribbon and rope fitted

Reinforcement of the cam as shown in Figure 4.68 to 4.70 has been designed to provide adequate support to the ribbon and changes its angle as sley oscillates. Also, bearing with bearing mounting bracket has been integrated with glass fiber with the cam like composite material. 5-wheel gear mechanism for take up motion is shown in Figure 4.71 and 4.72.

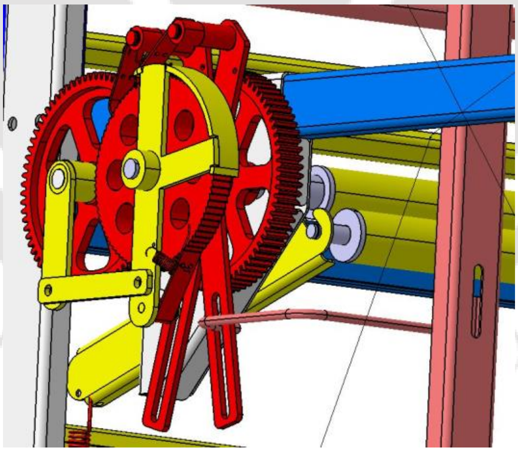


Figure 4.71: 5-Wheel gear mechanism isometric view of De-sign semi-automatic handloom

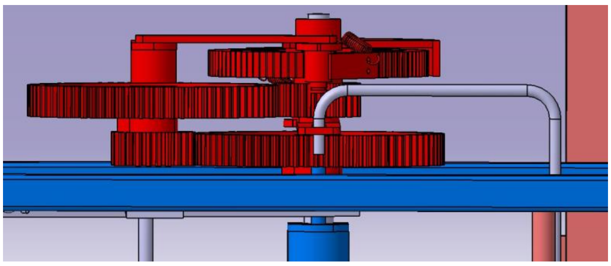


Figure 4.72: 5-Wheel gear mechanism top view of De-sign semi-automatic handloom

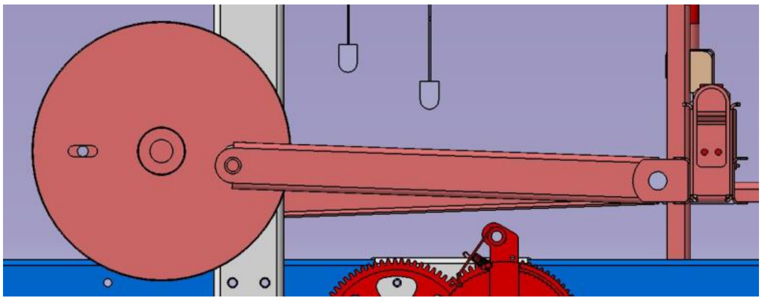


Figure 4.73: Crank with flywheel mechanism of De-sign semi-automatic handloom

A small counterweight of 500g is needed on the flywheel's as shown in Figure 4.73 inner side for smooth rotation during sley movement through the main shaft.

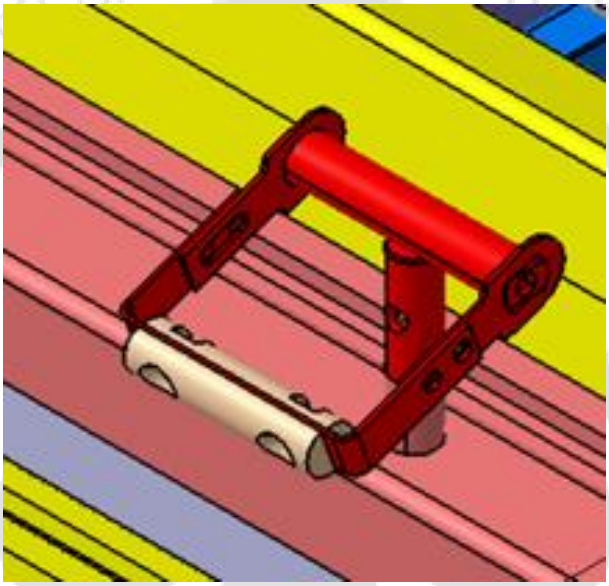


Figure 4.74: Handle for beat-up in De-sign semi-automatic handloom

Handle shown in Figure 4.74 needs to be adjusted considering maximum spine bend of 10 degrees with 5th percentile body dimension to incorporate all weavers with different body sizes.

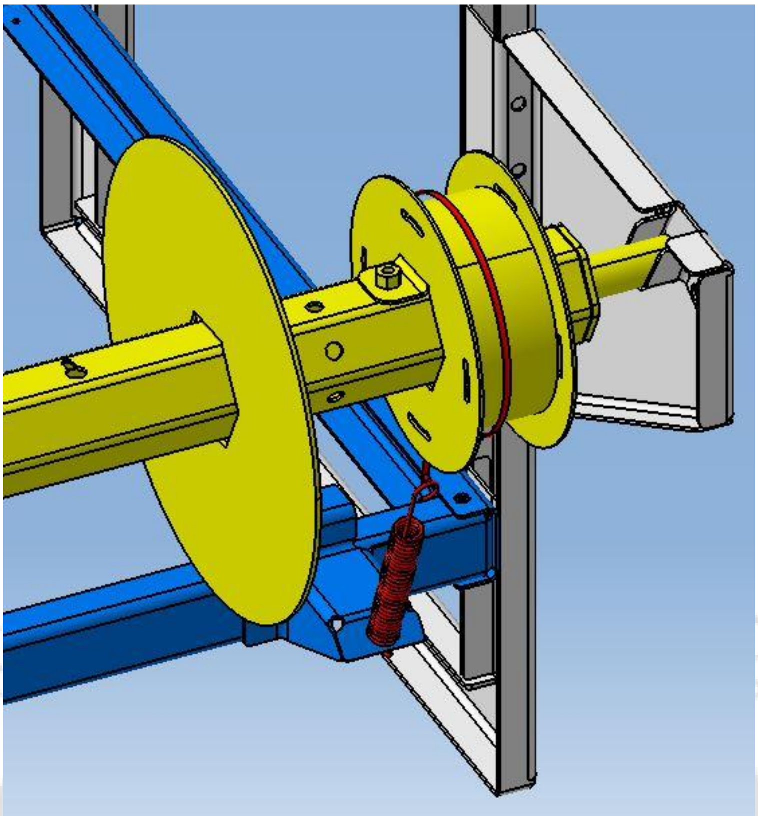


Figure 4.75: Warp flange sheet metal type from inside in De-sign semi-automatic handloom

Casted flywheel and wooden spring rope holder were eliminated and designed with sheet metal as shown in Figure 4.75, providing a laser-cut slot for easy weld assembly. Round beams have been changed to hexagonal to reduce slippage during let-off motion. Also, the hexagonal beam has provision to accommodate a group of warps.

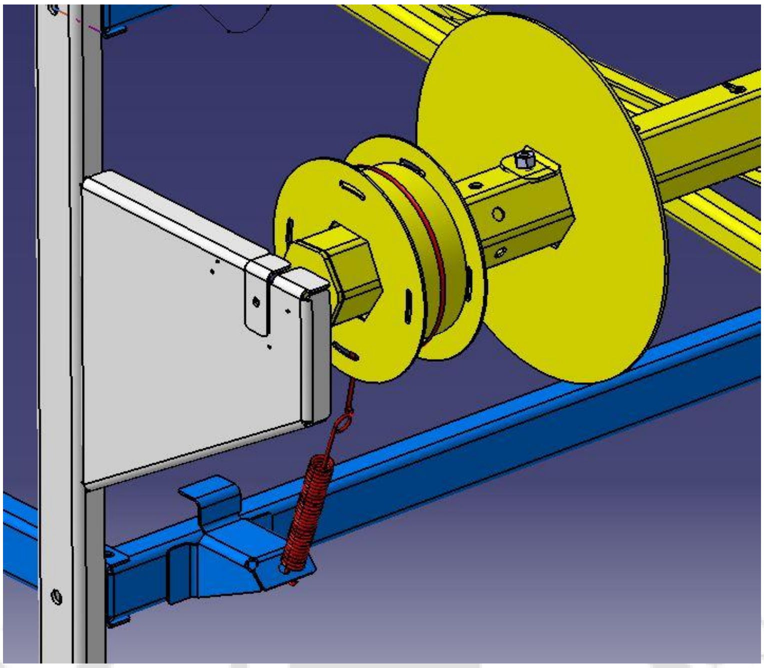


Figure 4.76: Warp flange sheet metal type from outside in De-sign semi-automatic handloom

A top cover on pivot pin along with external support provided to fall of warp beam during weaving as shown in Figure 4.76. Sometimes bottom support of the warp beam might move away due to the spring back nature of sheet metal when connected with the side frame.

The following Figure 4.77 to 4.79 depict some redesigns made in the alpha to beta model.

Figure 4.77: Let off spring bracket comparison in alpha and beta model

Figure 4.78: Warp beam holding bracket comparison in alpha and beta model

Figure 4.79: Cloth beam holding bracket, comparison in alpha and beta model

Oscillating backrest design is very critical due to load fluctuation of warp for shedding. This problem may increase further if take-up and let-off motions do not perform simultaneously. Square tubes are good with diagonal orientation, as shown in Figure 4.81, with significantly less contact area of warp yarn. Oscillating backrest with square tube orientation, as shown in Figure 4.80, increases the contact surface of warp yarn, which leads to the possibility of warp yarn breakage.

Figure 4.80: Oscillating backrest with square tube

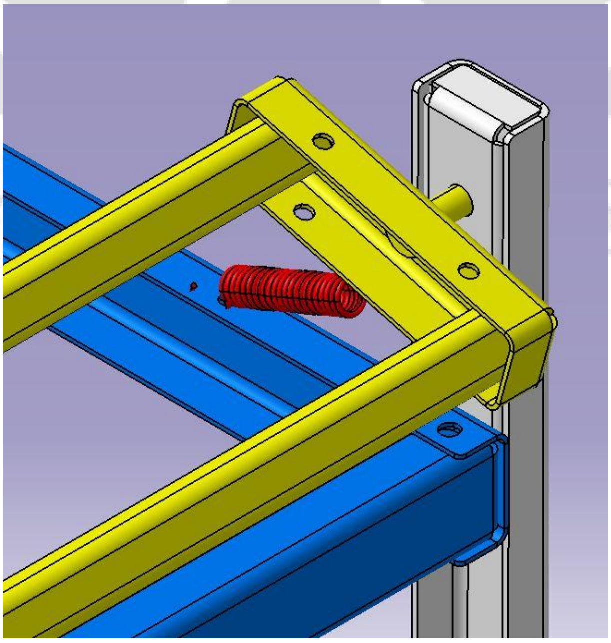


Figure 4.81: Oscillating backrest in De-sign semi-automatic handloom

The Poka-yoke concept applied for not assembling the assembly incorrectly by preventing or adding some hurdle in the way to the wrong way of the assembly process. Spring mounting holes are added in all four locations, as shown in Figure 4.81, to avoid such problem.

4.5.6 Manufacturing of Beta model

The beta model structure comprises sheet metal of 2mm, 3mm, 5mm, and one part of 8mm. This manufacturing method is adopted also in manufacturing winding wheel, warping drum, creel, jacquard, and seating system.

Initially, sheet cutting is done by laser cutting. It needs a template as a tool path to cut the profile as required. It is vital to nest all parts with equal thickness by arranging them optimally to improve material utilization. Few small-sized parts are connected to avoid the problem of missing out on those parts in debris beneath the bed of the laser cutting machine. The same bending is another reason to group them. Laser cutting nesting templates for a single loom are shown in Figure 4.82 to 4.85. Material efficiency will improve in case of larger lot sizes during laser cutting. Every corner has been given a proper fillet radius for laser cutting.

Nesting template

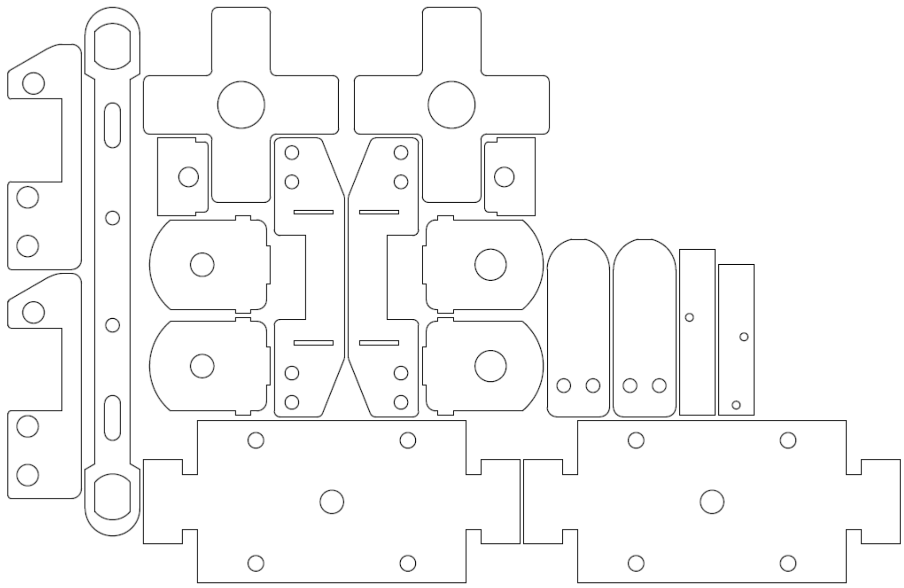


Figure 4.82: Profile for laser cutting with only cutting profile

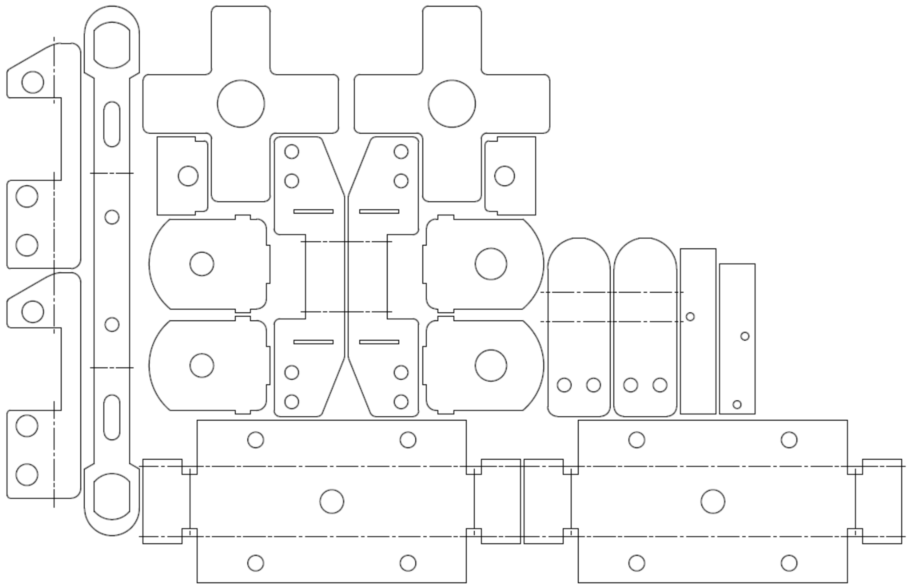


Figure 4.83: Profile for CNC bending with bend line

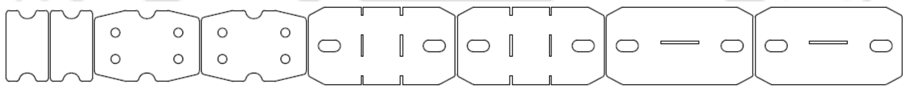


Figure 4.84: Profile for laser cutting with only cutting profile

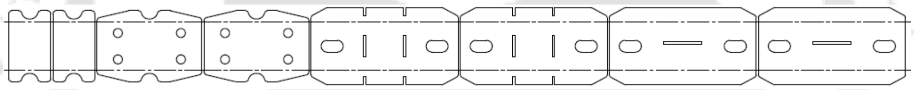


Figure 4.85: Profile for CNC bending with bend line

The Laser cut parts are for showing the purpose of connecting them in Figures 4.82 to 4.85. There are many more similar sets designed. Also, there is no joining between the parts shown. These are done at the vendor end based on the shortest tool path. The following processes are like bending, as shown in Figure 4.85 for a set of bending parts.

A laser cutting machine as shown in Figure 4.86 is used for cutting as the thickness of all sheets is below 10mm. CNC bending machine shown in Figure 4.87 and 4.88 is required for accurate bending to keep the hole location within the limit.

Figure 4.86: Laser cutting machine

(Source:https://www.indiamart.com/proddetail/fiber-laser-cutting-machine-19952325212.html)

Figure 4.87: Front and Rear view of CNC bending machine

(Source: https://www.aliexpress.com/item/32970883339.html)

Figure 4.88: Enlarged view of the bending area in the CNC bending machine

CNC bending can keep many punches in a single setup, and back side support is programmed to keep at an appropriate distance during each bend. After CNC bending, the dimension of parts is found repeatable and consistent. Bending is possible for even complex parts, as shown in Figure 4.89.

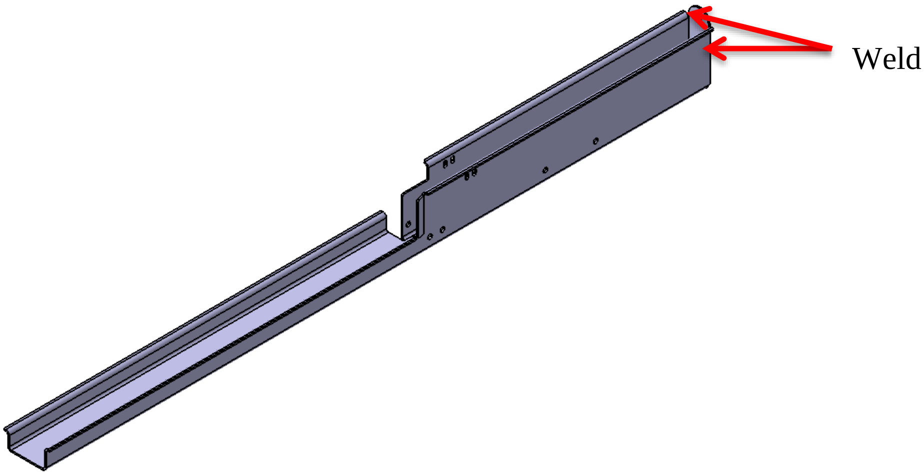


Figure 4.89: Sheet metal part after laser cutting and CNC bending

After bending, some corner joints are welded by TIG or MIG welding as most parts have 2-3 mm thickness. Welding is to be done with utmost care otherwise it may not flush or level as shown in Figure 4.90.

Figure 4.90: Joining and Welding defect

All these welding joints, then assembly are done based on the detailed drawing of the part as below in Figure 4.91

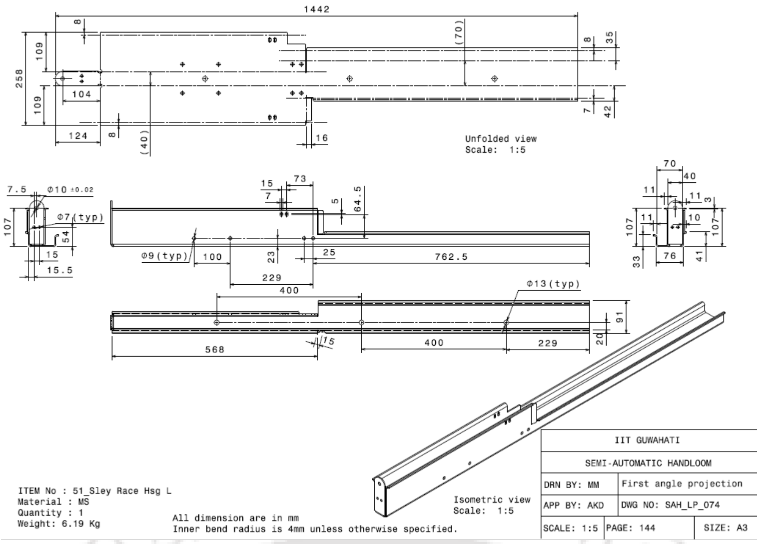


Figure 4.91: Example of manufacturing drawing of a sheet metal part

There are 75 unique sheet metal parts in the semi-automatic handloom, including accessories, i.e., spinning wheel, creel, warping drum, and jacquard. Similarly, there are xx unique round parts, seven unique wooden parts, one fiber part, casting parts, 13 purchase items, and 23 fastener items required in a handloom set. The detailed bill of material (BOM) of semi-automatic handloom, creel / stand, warping drum and winding wheel are shown in appendix 1 to Appendix 4 respectively.

Figure 4.92: Round parts used in semi-automatic handloom

Few round parts are manufactured in a turning machine, as shown in Figure 4.92.

Sley race and reed cover are made of pine wood whereas shuttle box is made of sheet metal. Cam is also developed in fiber material to increase strength and durability. Cam was made up of wood during the alpha model.

Once all the parts are manufactured, a few parts are assembled together as sub-assembly for ease of final assembly at the working location. Also, it helps to improve transportation with less number of parts. The chances of damage during transportation are reduced if few parts are assembled. Manufacturing defect at part level is detected very early to rework. Chances of missing out on small parts are also nullified with sub-assembly. An example of a sub-assembly drawing is shown below in Figure 4.93

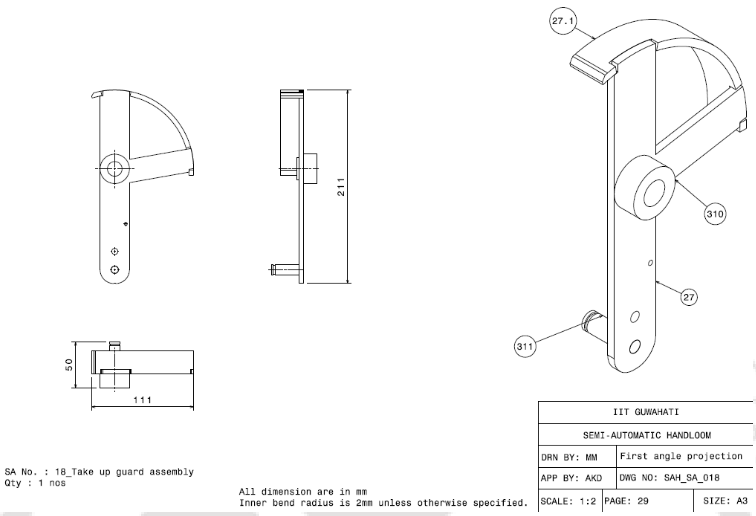


Figure 4.93: Example of sub-assembly drawing

There were few damages shown in Figure 4.94 found during packaging and transportation due to sheet metal nature of majority of the parts.

Figure 4.94: Initial packaging of sheet metal part/products

Figure 4.95: De-sign semi-automatic handloom without jacquard (beta model) from the left front at DoD, IIT Guwahati workshop

This semi-automatic handloom shown in Figures 4.95 and 4.96 has been improved by adding reinforcement throughout the side frame of 50mm width to reduce vibration during weaving. The final semi-automatic loom has a side frame of 75mm width with little short reinforcement, as shown in Figure 4.97.

Figure 4.96: Design semi-automatic handloom without jacquard (beta model) from the right front at DoD, IIT Guwahati workshop

Figure 4.97: Semi-automatic handloom at customer location

Figure 4.98: Enlarged view of Picking and beat-up mechanism

Enlarged view of picking and beat-up mechanism can be seen in Figure 4.98. Critical characteristics and potential risks at various stages of manufacturing have been identified in Table 4.4 below to improve quality and reduce lead time.

Table 4.4: Identification of critical characteristics and potential risk of the loom parts

Stages	Critical characteristics	Associated / Potential Risk
Supplier quality inspection	MS sheet metal bend / unbend parts	Handling / Packaging damage
		Spring back
		Thinning
		Shifting of laser cut hole position after bending
		The form does not match with fitting parts
	Round parts	Oversize
		Undersize
		Wear and tear
		Irregular GD&T
	Bright bar	Rust
	Casted/Machined Gears	Oversize the fitting hole
		Undersize the fitting hole
	Fiber parts	Thin to withstand the force
		Crack formation on holes created
	Wooden parts	Wear & tear
		Rough surface due to regular use
		Other than Bonsoom wood used
	Bought-out items (Bearing, Plummer block, Pulley, Belts, Ropes)	As per specs and quantity required
	Nylon parts	Void free nylon
	Fasteners	No chemical treatment like black oxide after assembly
Sub-assembly		Part size mismatch
		Distortion after assembly/welding
		Incorrect orientation
		Incorrect part quality
Assembly		Incorrect part/sub-assembly quality
		Functional issue

The function of the Semi-automatic handloom

Sub-assembly and part callout are shown below drawings to describe the function later with their callout number:

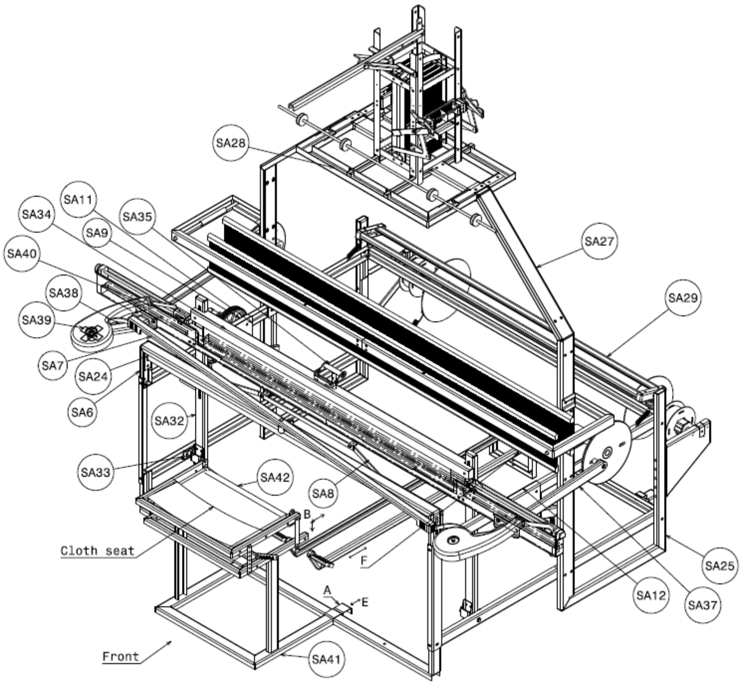


Figure 4.99: Isometric view from the front right of a semi-automatic handloom

Figure 4.99: Isometric view from the front right of a semi-automatic handloom showing various 'welded sub-assembly' considering manufacturing aspects, represented as SA27, SA28 etc., and adjustable system with direction as A, B etc.

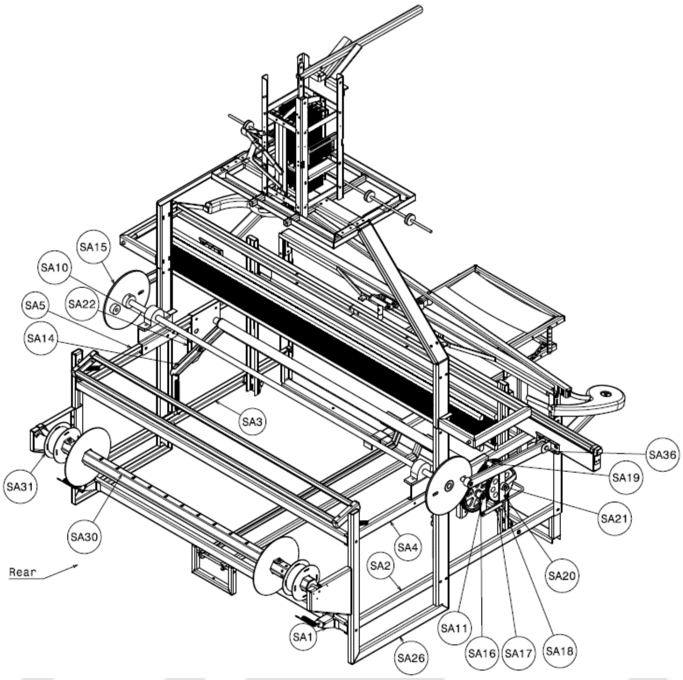


Figure 4.100: Isometric view from the rear left of a semi-automatic handloom

Figure 4.100: Isometric view from the rear left of a semi-automatic handloom showing various ‘welded sub-assembly’ considering manufacturing aspect, represented as SA1, SA2, and so on.

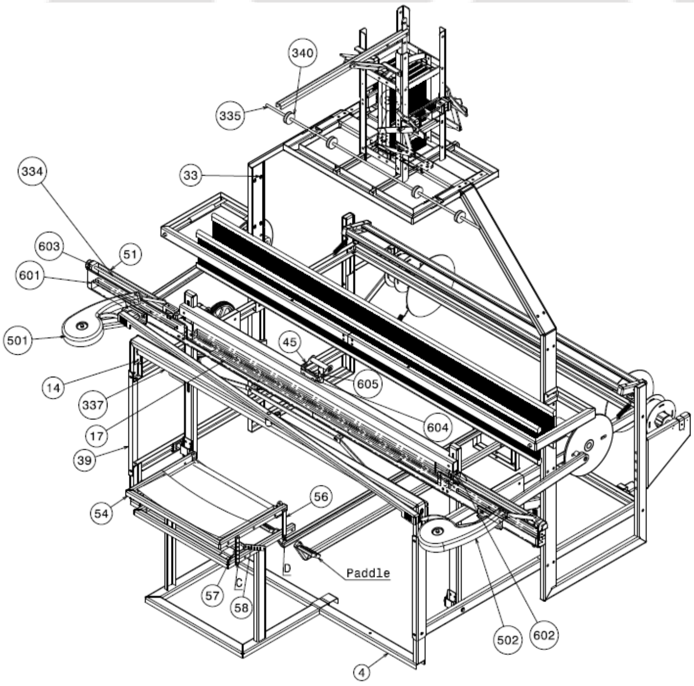


Figure 4.101: Isometric view from the front right of a semi-automatic handloom with jacquard

Figure 4.101: Isometric view from the front right of a semi-automatic handloom showing various 'individual parts' considering manufacturing aspect, represented as 57, 58 etc.

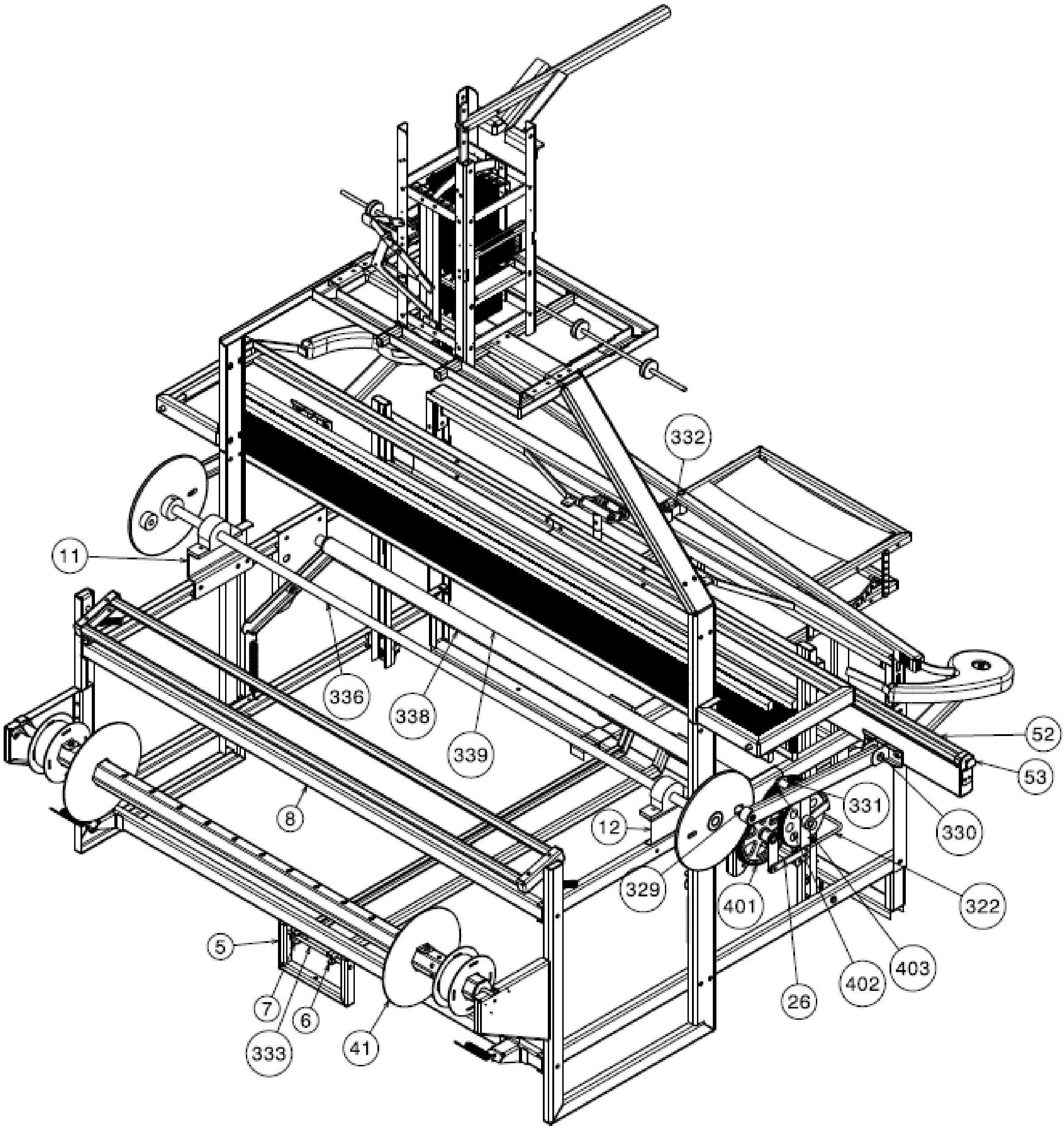


Figure 4.102: Isometric view from the rear left of a semi-automatic handloom with jacquard

Figure 4.102: Isometric view from rear left of a semi-automatic handloom showing various 'individual parts' considering manufacturing aspect, represented as 5, 6 etc.

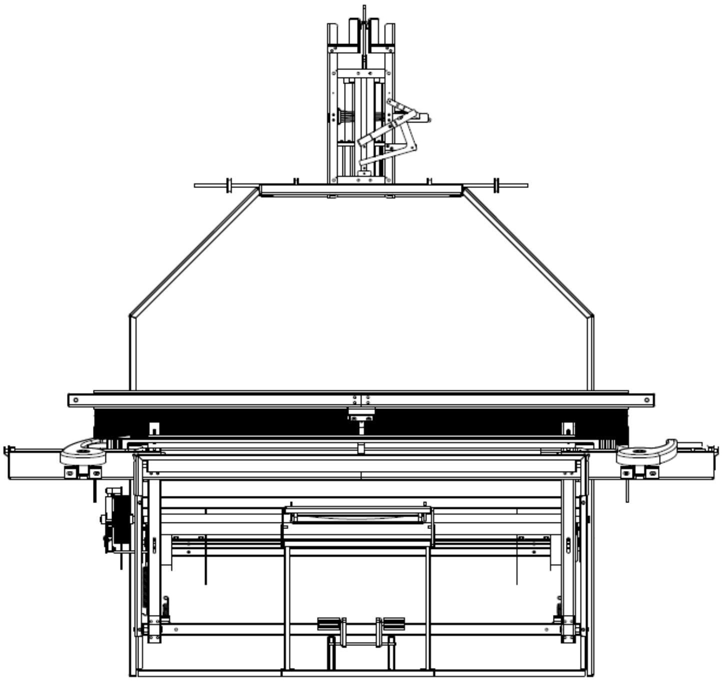


Figure 4.103: Front view of a semi-automatic handloom with jacquard

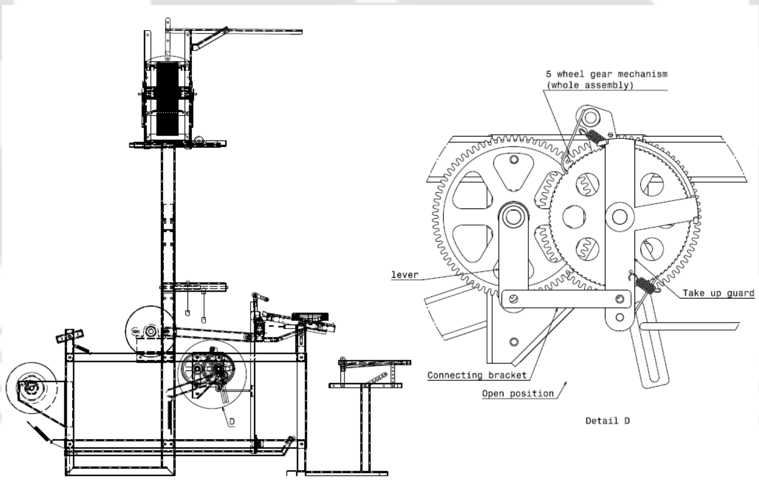


Figure 4.104: Side view of a semi-automatic handloom with a detailed view of the 5-wheel gear mechanism (side view) for take-up

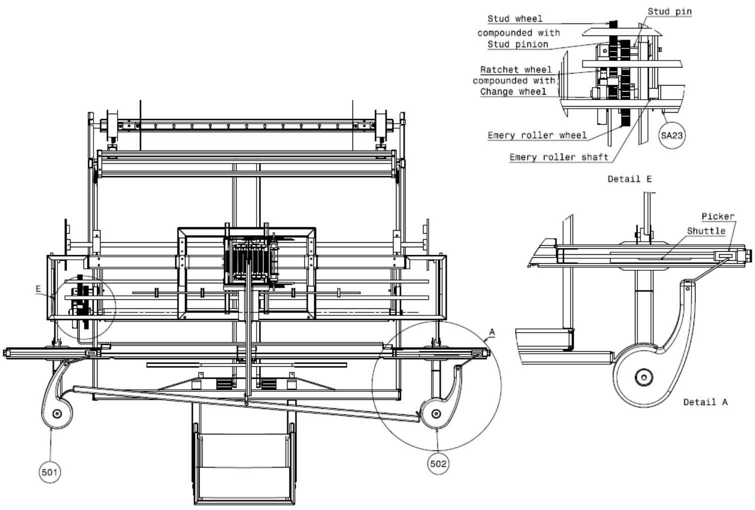


Figure 4.105: Top view of a semi-automatic handloom, detailed view of a 5-wheel gear mechanism (top view) for take-up, and Burmese type of under hung picking mechanism

Detail description of accompanying drawings

Drawing Figure 4.99 to 4.102 shows the isometric view of the semi-automatic handloom. Drawing Figure 4.103 to 4.105 shows the orthographic projections with a detailed view of the picking mechanism and 5-wheel gear mechanism. 'Structure of the handloom and adjustable seating system' are on C-section sheet metal steel structure which is strong enough to weave comfortably with manual shedding and beat-up motion.

There are three primary motions, i.e., shedding, picking, and beat-up, with two secondary motions, take-up, and let-off, along with a few tertiary motions. Shedding is independent of picking and beat-up motions to facilitate weaving structural design cloth and extra ornamentation. There should be proper reachability from the seating system's popliteal height to the treadle's paddle (6, 7) shown in Figure 4.102 for comfortable shedding. The wrist of the straight arm to sley handle (604, 605) shown in Figure 3 reachability in sitting posture is also very important for beat-up motion with minor leaning or without leaning of the upper body. This reachability will be accurate if the distance between the sley handle and paddle of the treadles is with mean body dimensions along with the adjustment to 5th percentile and 95th percentile body dimensions. These adjustments are provided in the seating system and treadles as below details for ergonomically comfortable shedding and beat-up motion manually.

The adjustable seating system has two-way adjustments, i.e., vertical and horizontal adjustments, as shown in Figure 4.99. Cloth seat holder (SA42) with cloth seat shown on page 1 and adjustable structural part (54) shown in Figure 3 of adjustable seating system cumulatively adjust vertically and horizontally along with pivot point as C and D shown in Figure 3. The adjustable seating system also has another horizontal adjustment at point E, shown in Figure 4.99, stabilizing the adjustable seating system with the semi-automatic handloom. Treadles (6, 7) shown in Figure 4 has adjustment horizontally shown as F 'pointed area of adjustment' by an arrow in Figure 4.99. Treadles can also be minor adjustments vertically with the ropes connected between the treadle and pulley (340) shown in Figure 4.101.

After shed formation, it must manually position both the cam (501, 502) as shown in Figure 4.105. The shuttle (shown in Figure 4.105) will be touched to the picker (shown in Figure 4.105) in the sley race (601) towards the right-side cam (502), as shown in Figure 4.105. Sley will be at the far position from the front for beat-up motion. To initiate weaving, sley oscillates towards the front for beat-up motion after shedding for automated picking in synchronization with beat-up motion. Sley oscillates for beat-up with the help of a crank (SA37) connected to fly wheel SA15) on both the left and right side of the semi-automatic handloom. Beat-up is done with a unique handle (SA35, 45, 604, 605) ergonomically designed, which can be operated by both left and right hand, comfortable for wrist with proper alignment of wrist and arm during oscillation of sley.

An actuating bend rod (322) attached to the sley sword (SA32) is used to operate a 5-wheel gear mechanism for automatic take up. Take up works in conjunction with the sley sword's reciprocating motion. When the ratchet wheel (402) comes forward with driving pawl (SA19) movement through bend rod (322) of oscillation of sley, the pick-up ratchet wheel (402) slides over the take-up guard (SA18) and, in the reversing motion, pulls forward the ratchet wheel with locking pawl (SA20) as per the setting of the pick spacing. Also, the take-up mechanism is modified to house all the five gear wheels on only two shafts (SA11, SA21). 'Ratchet wheel is compounded with change wheel (402)' mounted freely on the emery roller shaft (SA21), which drives the 'stud wheel compounded with stud pinion (401)' and mounted freely on the stud pin (SA11). The stud pinion (401), in turn, drives the emery roller wheel (403), which is fixed onto the emery roller shaft. Adjustment of pick spacing is possible through the lever (SA16) mounted on the stud pin and secured to it with nuts and bolts. It holds the take-up guard (SA18) in a fixed position.

Let off mechanism works in conjunction with the take-up mechanism. The positive take-up of the woven materials generates tension on the warp sheet, and when this tension exceeds the spring-loaded let-off mechanism, it lets off the required amount of warp. Bracket for spring mounting (SA31) and warp flange (SA41) was developed through sheet metal to make a uniform manufacturing process. The warp beam is designed in a hexagonal shape against a round shape to avoid slippage through stainless steel sheet metal with the provision to put all knots of each set of warp yarns inside the warp beam.

The temple mechanism also works when the woven cloth is taken up. The rollers inside the temple mechanism roll to allow the cloth to come forward for rolling onto the cloth roller. The bracket to locate the end locater profile was designed to control the width of the fall without affecting beat-up motion.

The oscillating backrest (SA29) is loaded with a spring to keep the warp sheet in uniform tension during shed formation. It only allows yielding the let-off mechanism after it has reached its limit and immediately takes up any slackness resulting from shed closing. This assembly is also made out of sheet metal, with proper testing for bending due to tension during weaving.

Chapter 5: Design and manufacturing of accessories of Semi-automatic handloom

It is found that accessories in pre-weaving, seating system, and jacquard for weaving with ornamentation also need to be synchronized with a Semi-automatic handloom. Therefore, the accessories below have been redesigned for durability and mass manufacturing.

5.1 Design of accessories for Semi-automatic handloom

5.1.1 Design of Winding wheel

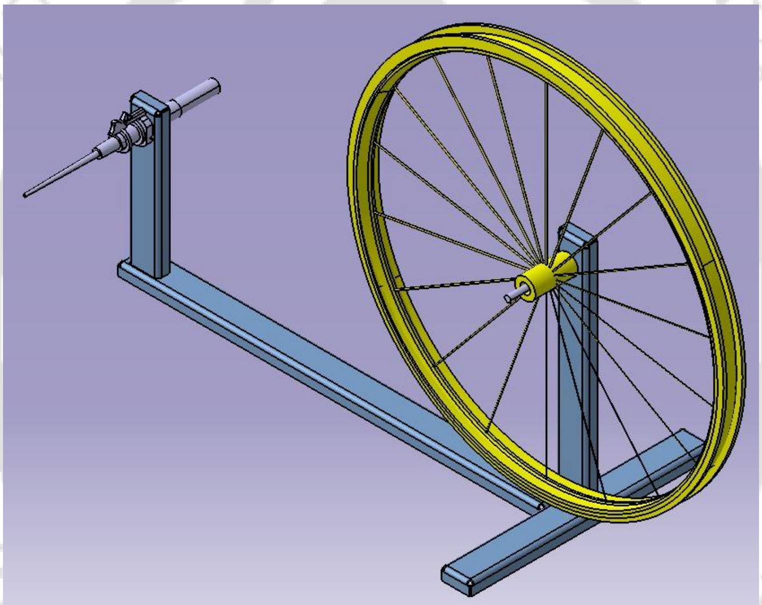


Figure 5.1: Winding wheel / Charkha

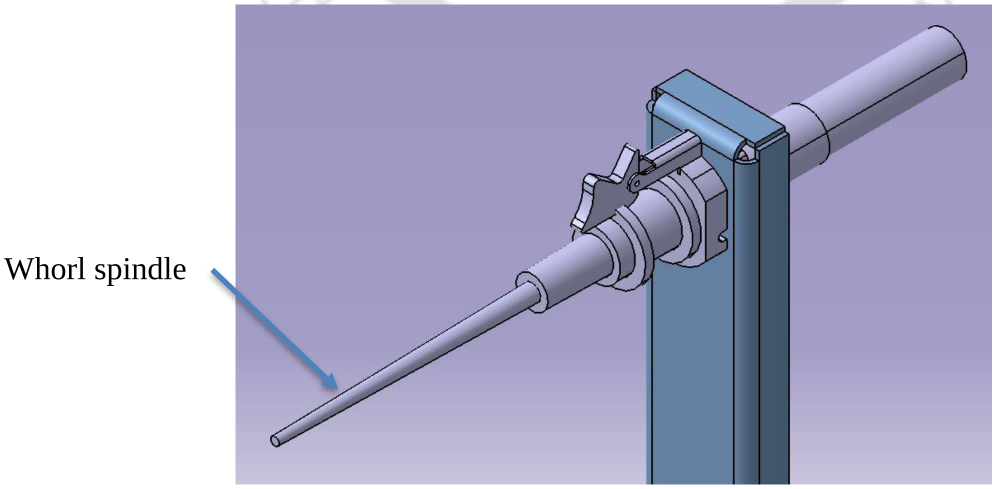


Figure 5.2: Removable whorl spindle of Winding wheel / Charkha

Winding helps to wind hank yarn in bobbins for warp yarn and pirn for weft yarn, as shown in above Figures 5.1 and 5.2.

5.1.2 Design of Complete Metallic Creel

Warping drum and creel design with sheet metal have shown below in Figure 5.3.

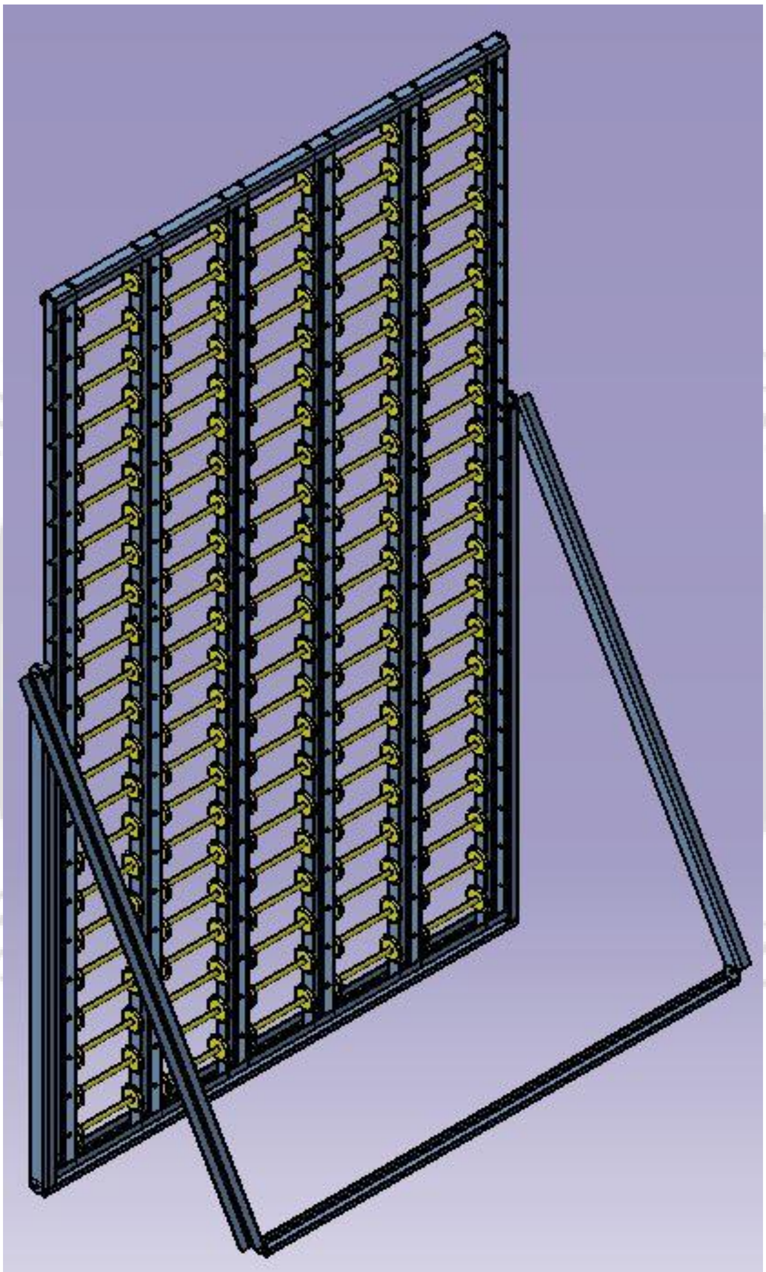


Figure 5.3: Creel

An enlarged view of the functional area of the creel is shown in figure 5.4.

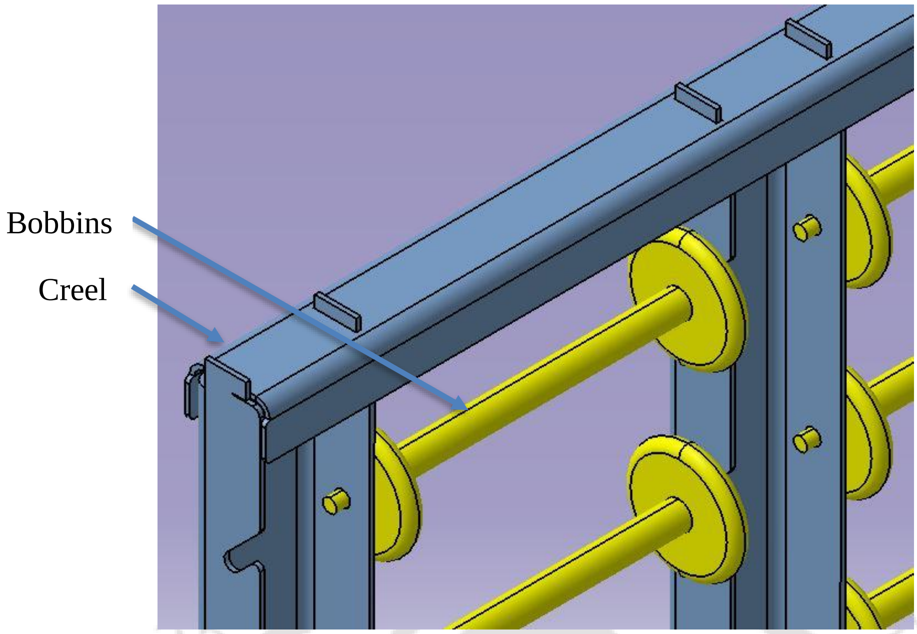


Figure 5.4: Enlarged view of Creel with bobbin

5.1.3 Design of Complete metallic Warping drum

Yarn from bobbin then goes to warping drum through the reed and between two rollers to close the set of warp. The warping drum looks as below fig. 5.5 at this stage.

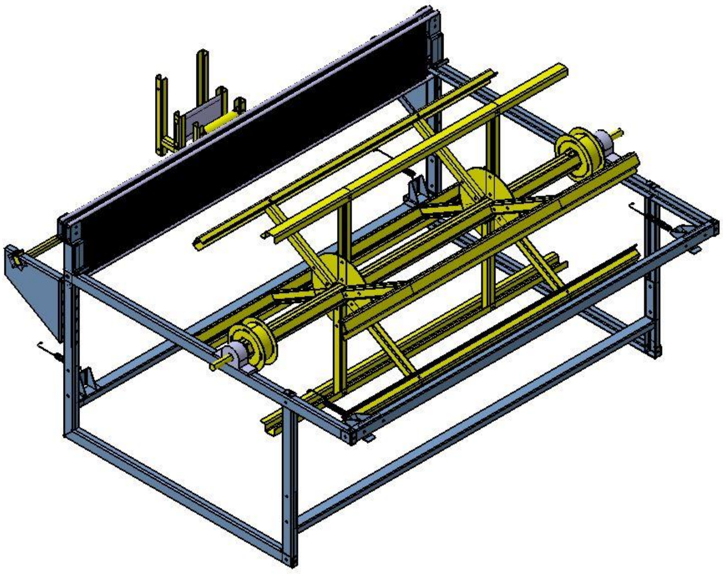


Figure 5.5: Warping drum to prepare warp sheet from bobbins in creel

All warp yarn has warped on warping drum from creel. After that, warp sheet from the warping drum is again wound onto the warp beam. Warping drum with warp beam is shown as below Fig. 5.6.

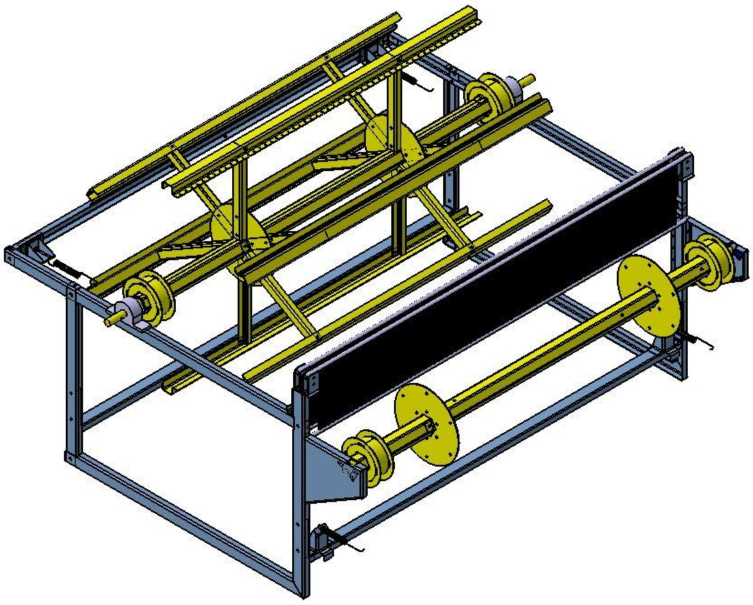


Figure 5.6: Warping drum to wind warp in warp beam

5.1.4 Design of Adjustable Seating system

The seat design is adjustable in height and distance from the front rest to accommodate weavers with different anthropometric dimensions. The new seat design in fabric provides the weaver a comfortable operational position with a back support that is not available with existing traditional looms used by the weavers.

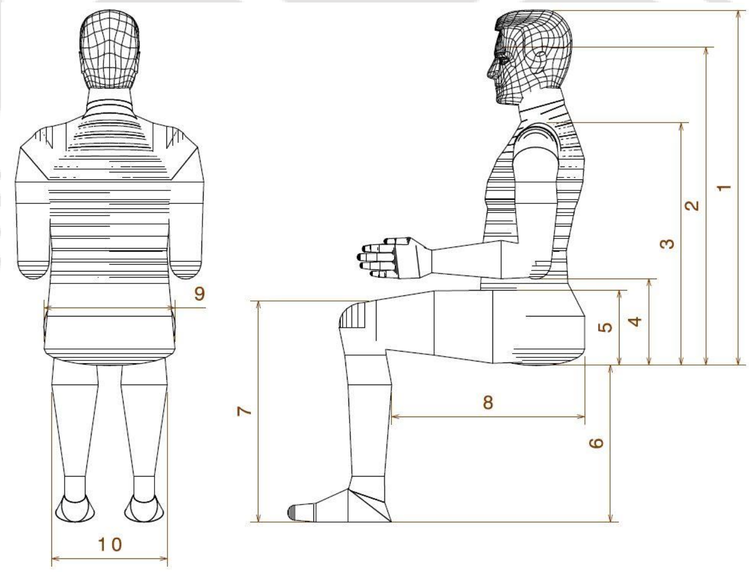


Figure 5.7: Anthropometry data considered in seating system design

The seating system is vital as it connects the weaver to interact with the loom. It should be at an appropriate distance and height for reachability for long-duration work.

Alpha-model is checked functionally. It has been working well as expected. In the beta model, we have eliminated all minor drawbacks found in the alpha model, like position shifting of the drilled hole due to tubular section. Arc welding was burning out thin sheets during arc welding to build the alpha model. The central focus was on low-cost, simple manufacturing processes suitable to make it in mass. Laser cutting and CNC bending manufacturing processes are considered to design significant parts of the seating system. 3mm mild steel sheet metal is used for all laser cut parts except linkage parts, which have been made with 5mm. TIG welding is used to weld wherever applicable for proper welding. This model can be easily assembled and disassembled, and efficiently packaged. Weavers from Sualkuchi and Artfed organizations with variations in weight and body dimensions have operated the handloom and found it comfortable in physical loom design by us. The beta model of seating system is shown in Figure. 5.8.

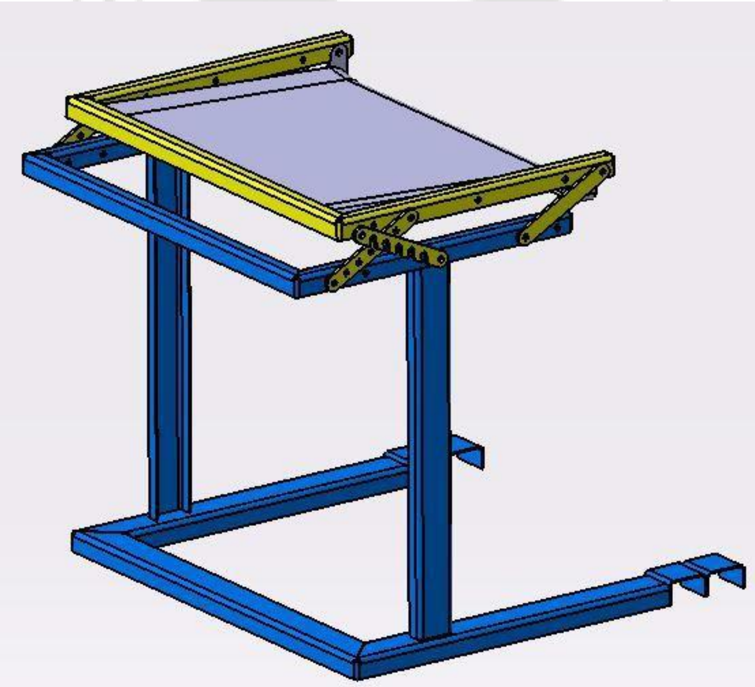


Figure 5.8: Adjustable seating system

This seating system has a large welded structure at the bottom to provide rigidity. It needs enormous storage space, which might be excellent for future work.

Our findings suggest that a minimum of 3 mm mild steel sheet thickness is needed for the structure of the seating system, and 5mm mild steel sheet thickness is needed for linkage parts. 125mm length link with a stop hole in every 25mm is used to accommodate the weavers' 5th to 95th percentile body dimensions for the central position of beat-up and shedding point. Figure 5.9 to 5.11 shows the reachability test with CATIA mankin.

This seating system is suitable with the De sign loom, a semi-automatic handloom. It can be manufactured for the mass requirement quickly and can support handloom cluster development.

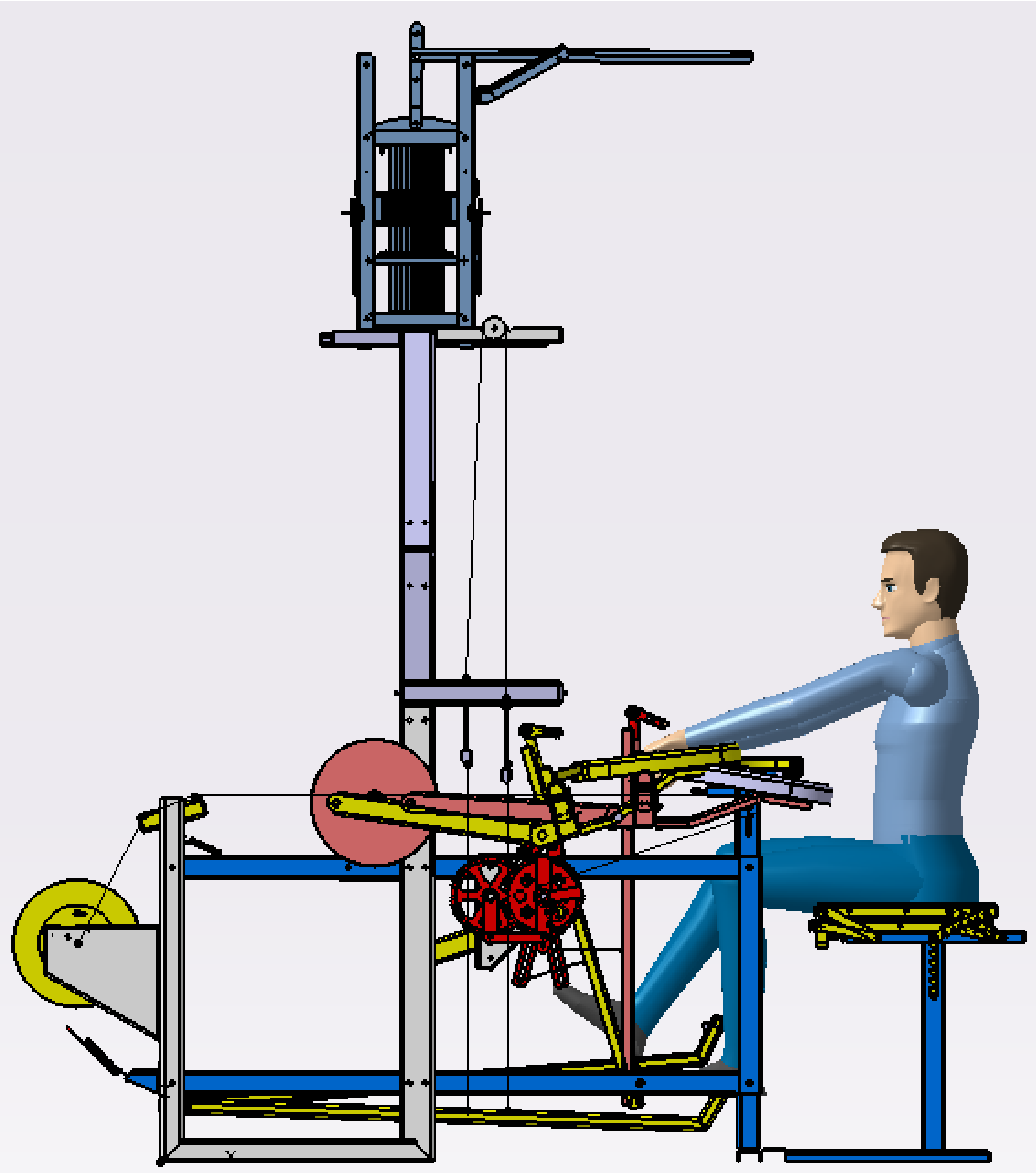


Figure 5.9: Mankin (5th percentile) with the seating system

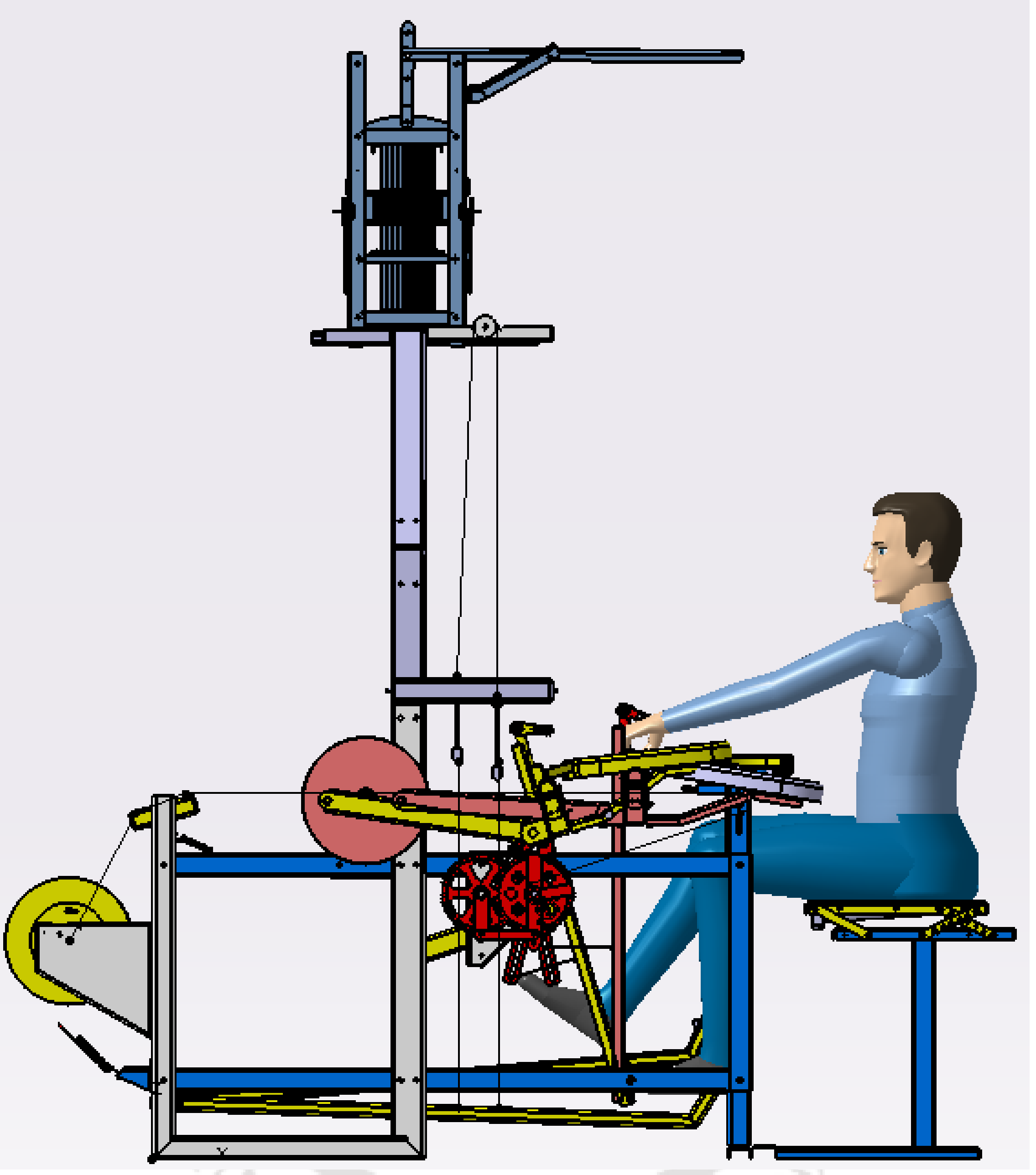


Figure 5.10: Mankin (50th percentile) with the seating system

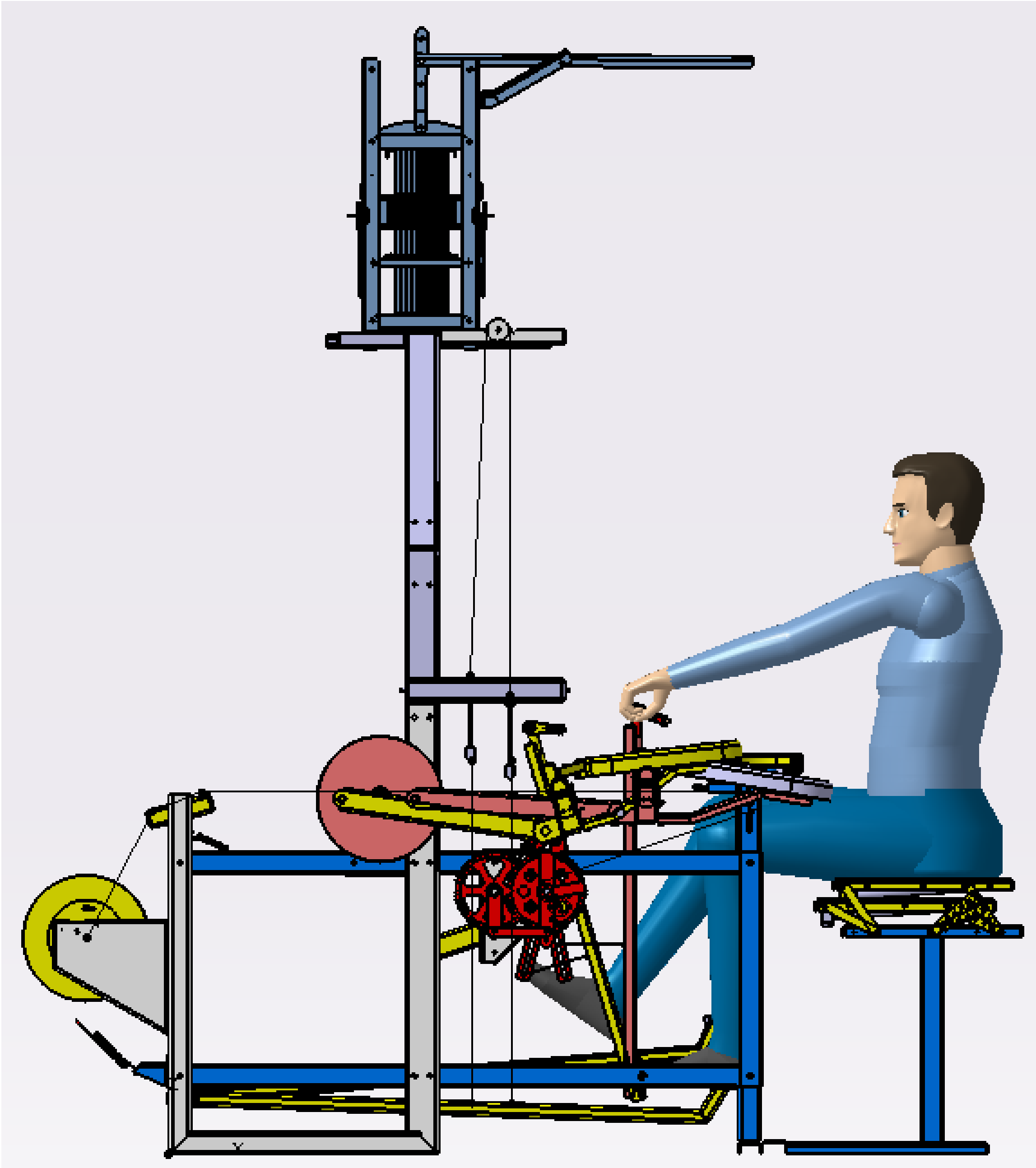


Figure 5.11: Mankin (95 percentile) with the seating system

Weaver has to adjust the seating position through adjustment for a proper reach of the leg to paddle. Treadle length can be adjusted through its pivot position for further leg positioning to treadle. Now, beat-up handle reachability needs to be adjusted through an adjustable bracket in the beat-up handle for easy beat-up.

The two Figure 5.12 and 5.13 below show the nomenclature of the human body as per CATIA ergonomics module.

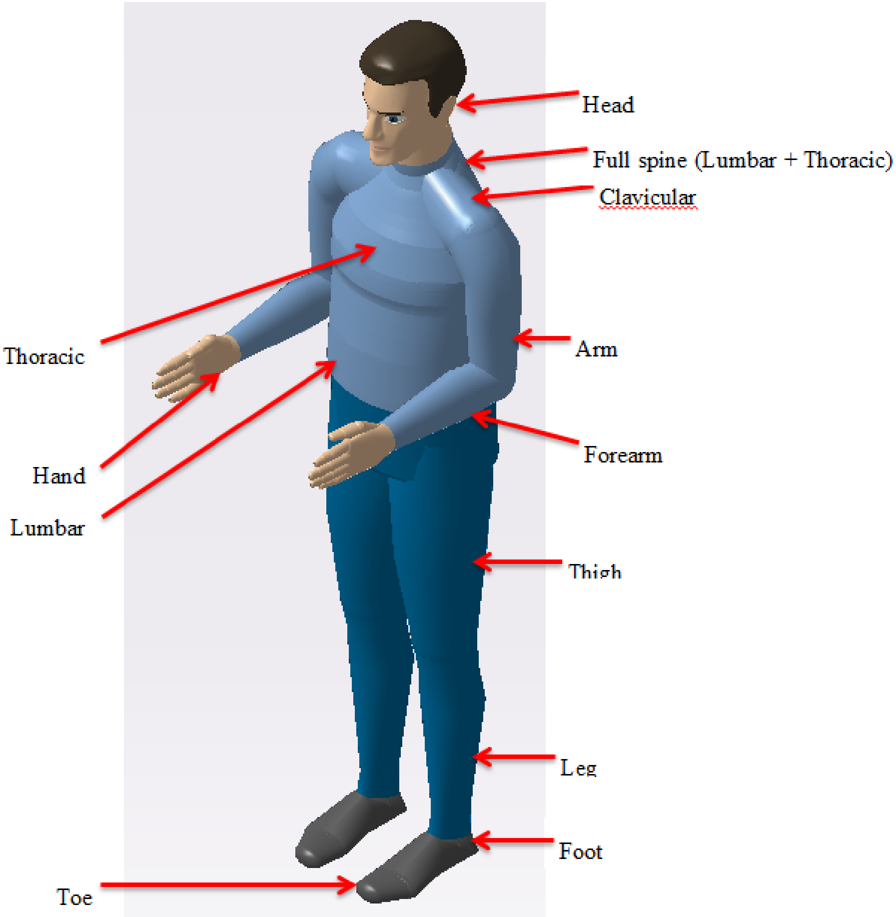


Figure 5.12: Nomenclature of the human body as per CATIA ergonomics module

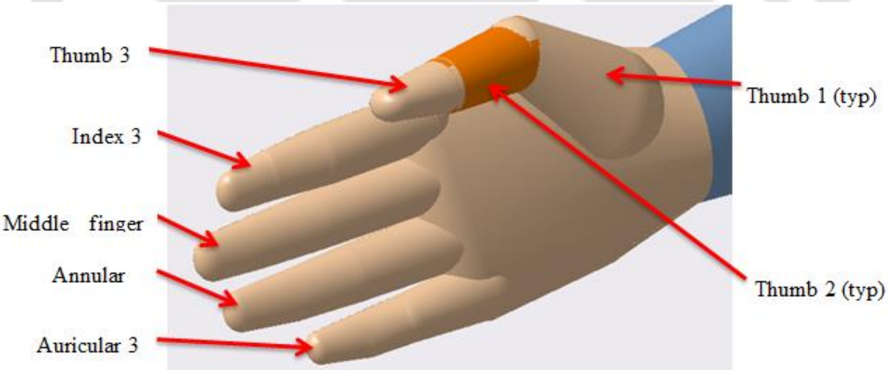


Figure 5.13: Nomenclature of the human hand as per CATIA ergonomics module

This seating system is limited to body dimensions with a fixed aspect ratio. Also, spare parts may not be available without proper supply chain and inventory management. Adjustment cannot be made below 25mm in this system, which can be improved further for micro adjustment.

This seating system can be imitated by professions like tailoring, driving, etc. where there is cyclic and dynamic work required by both hand and leg.

5.1.5 Design of Complete Metallic Jacquard

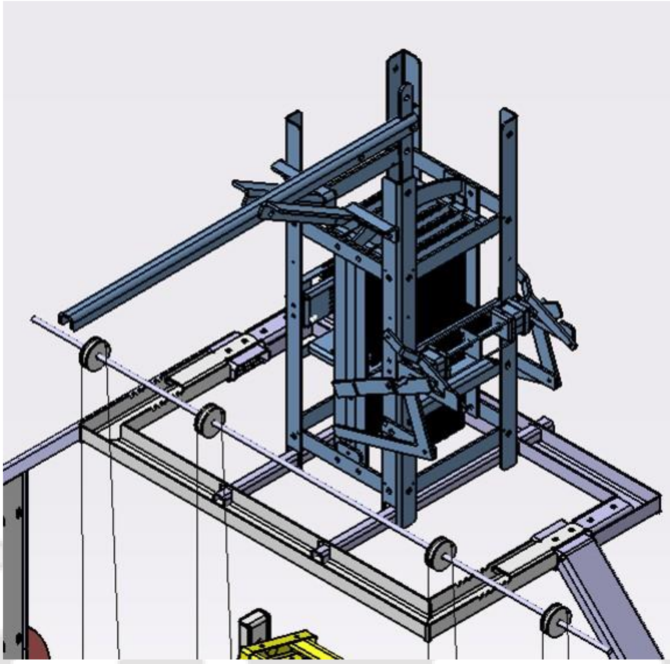


Figure 5.14: Jacquard with semi-automatic handloom

Jacquard was made initially with wood and metal mixed, which needed both fabricator and carpenter to manufacture. In the new design of jacquard shown in Figure 5.14, all make parts will be manufactured through laser cut and CNC bending, similar to the parts for semi-automatic handloom.

5.2 Manufacturing of accessories for Semi-automatic handloom

Make parts of all these accessories have been made through sheet metal for a uniform manufacturing process for all equipment. It will also help to manufacture these accessories in mass.

5.2.1 Manufacturing of Complete Metallic Creel and Warping Drum

The manufacturing of Complete Metallic Creel and Warping Drum are shown in fig. 5.15 and 5.16.

Figure 5.15: Warping drum with creel (Pre-weaving tools) with sheet metal formed mild steel structure

Figure 5.16: warping drum with creel at customer location

5.2.2 Manufacturing of Adjustable Seating system

Alpha-model of the seating system

Research on seating systems for weavers during weaving is a supplement to the ongoing research on Semi-automatic handloom. The seating system required for a weaver is similar to a stitching machine operated by a tailor. Also, it will be pretty similar to automobile drivers. Automobile driver engaged with non-repetitive work in his hand or leg. Tailor also gets some time for rest during the re-orientation of cloth. In the case of a handloom weaver, they have repetitive cyclic work for beat up and shedding motion.

We have done a field survey to examine the current practices in Sualkuchi, Assam. Weavers are using a stool or bench right now as a seating system. These seating systems are not adjustable to fit different body dimensions of the weaver. The ideal chair should properly adjust two body dimensions, i.e., popliteal height and Buttock – Popliteal length. More importantly, a dimension between sitting level to shoulder height is required for beat-up motion. Accordingly, a beat-up handle position needs to be designed in the handloom. Because peddle position of the treadle for shedding can be adjusted with the hanging rope according to the foot's position in a comfortable extended leg.

There is an extensive review made with all standard seating systems available online as well as offline concerning the ideal condition [2],[6],[7],[12]. An adjustable movable seating system for office was found somehow suitable since many of these have height adjustment and can move front and back with coasters. However, it is not considered for use in conjunction with handloom because, in handloom, work posture requires that the chair is fixed relative to the loom, and due to the lack of a locking system for movement restriction, these were not considered. Also, weaving does not need a back rest like an office chair, and the cost of these chairs is comparatively high.

Multiple health issues are observed in the literature due to the irregular repetitive posture at occupation. Therefore, new seating has been conceptualized to overcome the existing seating system. Popliteal height, Buttock – Popliteal length, Buttock to extended (rested on the floor) leg comfortable length are three primary body dimensions considered for shedding motion. Mid position length - forward arm reach with and without leaning are primary body dimensions for beat-up motion.

An alpha model of the seating system is conceptualized considering the low-cost manufacturing to reduce the cost. Parallel motion linkage or Four bar linkage mechanism adjust popliteal height and Buttock – Popliteal length. This mechanism was imitated from the pantograph of an electric railway engine. A quick fixing stopper is kept for locking the mechanism in the desired position. Anthropometric body dimensions were considered with 5th, 50th, and 95th percentile for adjustment to fit weaver with different body dimensions. It has multiple steps to fix to best fit any individual weaver as shown in Figure 5.18. It is designed with a 1" square section steel tube. Welding and drilling operations were used to make this model. Mild steel is used for strength and is automation friendly compared to wood. Alpha-model of seating system is shown in Figure 5.17.

Figure 5.17: Alpha-model of a seating system for handloom

Figure 5.18: Seating system for semi-automatic handloom

5.2.3 Manufacturing of complete metallic Jacquard

This handloom is suitable for both types of jacquard; one is made up of complete metallic frame jacquard, and another is wooden frame jacquard, as shown in Figure 5.19.

Figure 5.19: Semi-automatic handloom with wooden frame jacquard

Complete metallic frame jacquard can also fit similar way with a semi-automatic handloom.

Chapter 6: Findings and Discussion

6.1 Finding on shedding motion

Shedding motion with treadles performs well if it is adjustable to position the leg. Treadle material in steel trial was done with the following cross-section.

a b c d e f

Figure 6.1: Cross-section of treadles

The section in Figure 6.1 a of the treadle has difficulty adding holes for paddle fitting and back end mounting holes. The section in Figure 6.1 b and c are sheet metal mild steel section with 2mm and 3mm thickness, respectively. These treadles are twisting towards the opposite pivot end due to clearance between the pivot hole and pivot pin. The section in fig. 6.1 d and e work well but require two parts to be welded to form an enclosed section to restrict the twisting effect, as shown in Figure 6.1 a and b. The section in Figure 6.1 f is also avoided as it has a drilling problem in two sheets per side.

Distance between paddle for shedding as shown in Figure 6.2 and handle for beat-up is significant in seating system design for weaving based on anthropometry data. Paddle and handle movement of open and working positions are to be within permissible limits. Treadles can come close together as shown in Figure 6.3 due to lack of spacer and non-availability of guide throughout the length of the treadle.

There should be an option for adjustment on various sub-assemblies to achieve the above-mentioned working area. These adjustments can be achieved by adjusting the seating system, treadle, and handle for manual shedding and beat-up motion.

Figure 6.2: Sheet metal treadle with reinforcement

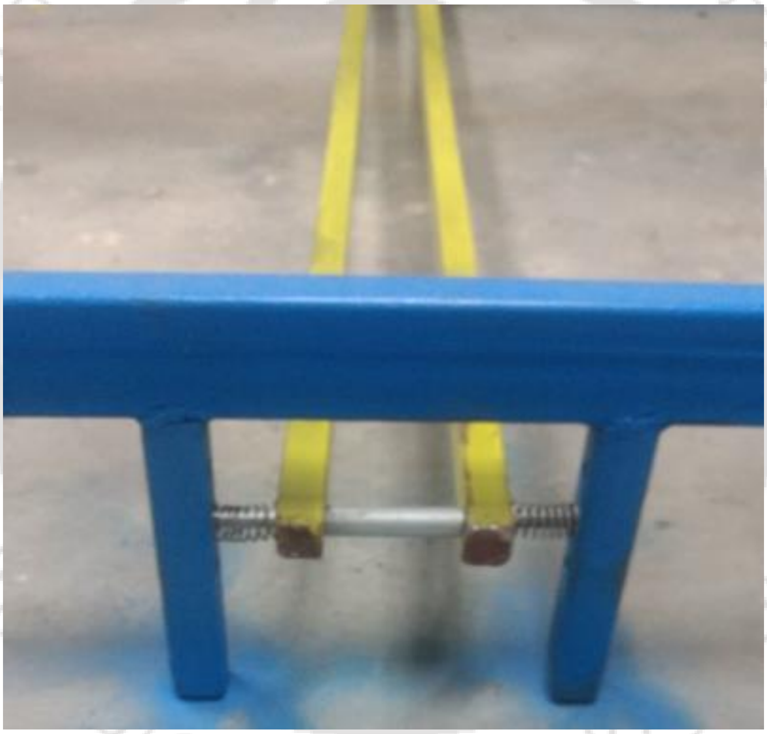


Figure 6.3 Treadles from backside

Seating system can be adjusted in three levels as below Figure 6.4 along with its interaction with the handloom for 5th percentile, 50th percentile and 95th percentile in Figures from left to right respectively.

Figure 6.4: Seating system with different adjustment

6.2 Finding on picking motion

Weaver Service Center, Imphal, has a Burmese picking mechanism with overhung sley. Therefore the structure should be heavy as shown in Figure 6.5, and a light structure is impossible. In this loom, much manual work is involved for take-up and let-off.

Figure 6.5: Burmese type of picking mechanism developed by some master weaver

Burmese picking mechanism with underhung sley is used with wooden cam in the alpha model of semi-automatic handloom. An ordinary rope and ribbon are used for cam action for picking.

Figure 6.6: Comparison of Cam mechanism for picking in alpha and beta model

Wooden cam is replaced by cam made with fiber material with an integrated bearing in pivot while developing a beta model of semi-automatic handloom. A unique rope and ribbon are used in the final model of the semi-automatic handloom. Difference in cam mechanism between alpha model and beta model is shown in Figure 6.6.

Picker has got damaged as shown in Figure 6.7 due to constantly hitting by shuttle through a sharp point which starts crack formation or a void in the plastic material. Leather layer is provided in the hitting surface to avoid this problem. Weight has to be checked before using the pickers, considering the density of the plastic material, to avoid void defects.

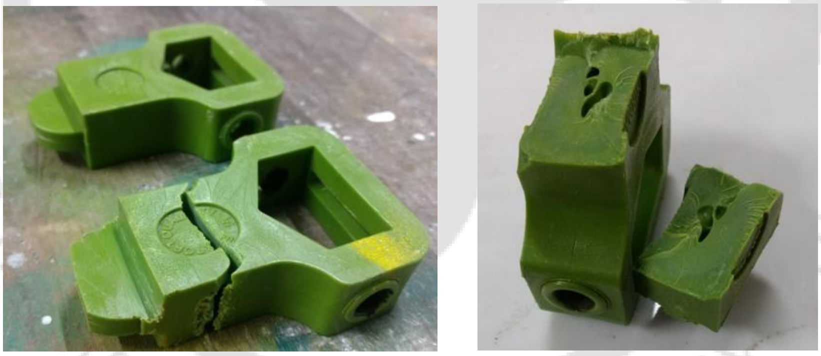


Figure 6.7: Picker with void

The shuttle requires a sharp edge to eliminate resistance-free movement without breaking warp yarns. Introducing a hole in the contact area of the picker increases the contact area, reducing the chances of picker breakage significantly.

Chaneki as shown in figure 6.8 an extra weft insertion device can insert multiple extra weft. It increase the productivity significantly.

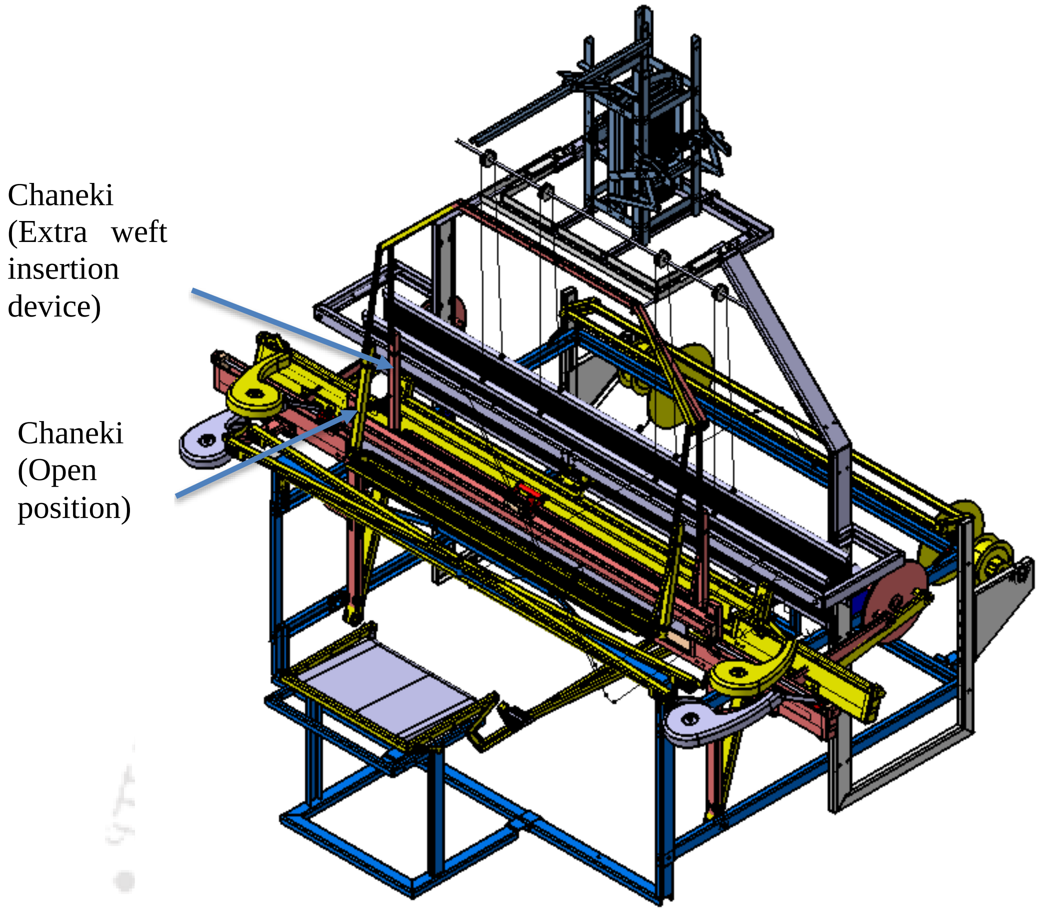


Figure 6.8: Semi-automatic handloom with Chaneki (Extra weft insertion device)

6.3 Finding on Take up and Let off motion

5-wheel gear mechanism can be seen in Figure 6.9 and 6.10.

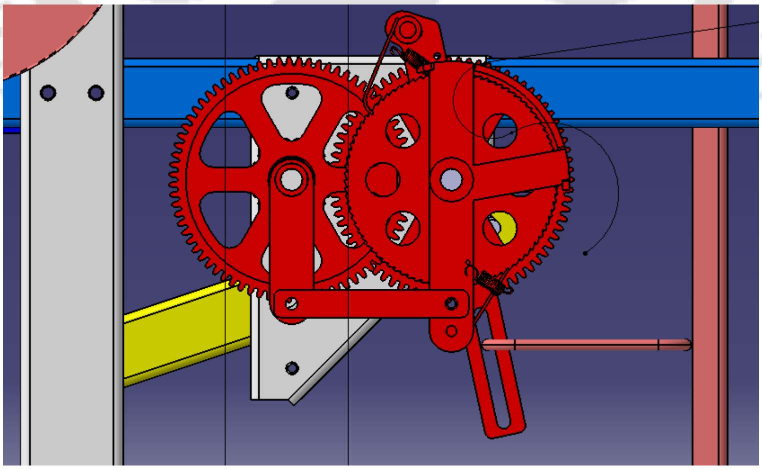


Figure 6.9: Front view of 5-wheel gear mechanism design in beta model

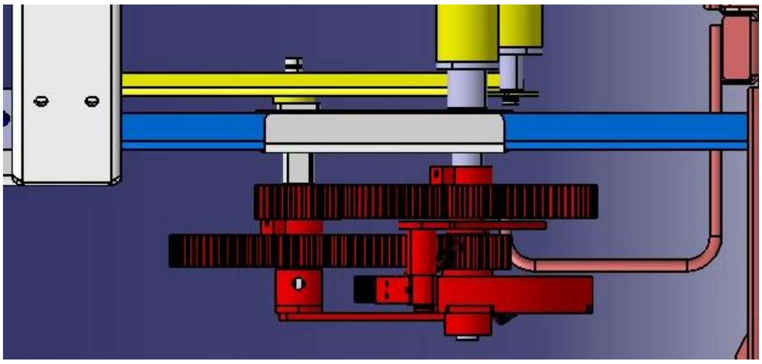


Figure 6.10: Top view of 5-wheel gear mechanism in beta model

Gears are final to use with various adjustment for different count of yarns. Physical model of 5-wheel gear mechanism is shown in Figure 6.11.

Figure 6.11: Front view of 5-wheel gear mechanism in beta model

The top actuator needs to engage or dis-engage based on the requirement of take-up motion during various stages of weaving.

It is observed to be, the frequent requirement of manual adjustment every 15 minutes in take-up motion for thin yarn fabric weaving. It might be due to improper parallelism between cloth roller and beam with emery paper along with front roller. Still, there is slippage problem in the cloth beam as shown in Figure 6.12.

Figure 6.12: Slippage of thin fabric in cloth beam

6.4 Finding of Beat-up motion

Flywheel design in alpha and beta model is shown in Figure 6.13.

Figure 6.13: Comparison of the flywheel in alpha and beta model

In the alpha model, flywheels were made through casting, followed by drilling or boring, which is a costly operation, whereas, in the current design, it is done through laser-cut an 8m plate. No further operation is required to provide the final shape.

6.5 Sheet metal Frame structure

Initially, the whole structure was designed through 2mm thickness, considering the uniformity among all the parts. Also, Alpha model structure was made up of 2mm thickness rectangular tubular structure with 50 x 25 mm cross section. Therefore, beta model was started with 2 mm thickness as beginning. During the trial, few parts could not bear the force exerted during the weaving operation.

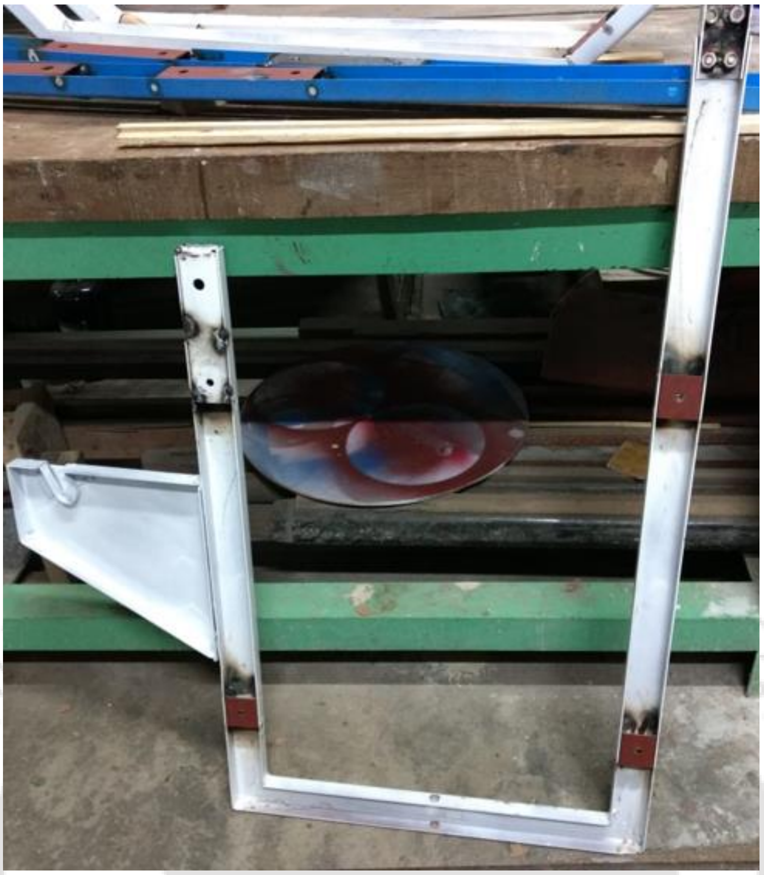


Figure 6.14: Side frame with 2mm sheet thickness and 50mm width

Figure 6.15: Side frame with 2mm sheet thickness along with reinforcement

Figure 6.16: Side frame with full reinforcement

Figure 6.17: Side frame of 75 mm width with small reinforcement in two-way fitting

Therefore, some parts were modified to 3mm from 2mm thickness to check the performance. Also, it requires resizing and adding reinforcement in some parts/sub-systems. Below shown parts are modified into 3mm in the beta model like treadle, Front top frame for cam actuator bracket, Side frame as shown in Figure 6.14 to 6.17, Jacquard mounting/pulley holder for shedding, Warp support in warp beam, Cam holding bracket, Reinforcement of cam holding the bracket in bend area, Sley race mounting bracket LH/RH. Few links are used in 5-wheel gear mechanism; the seating system is made up of 5mm thick.

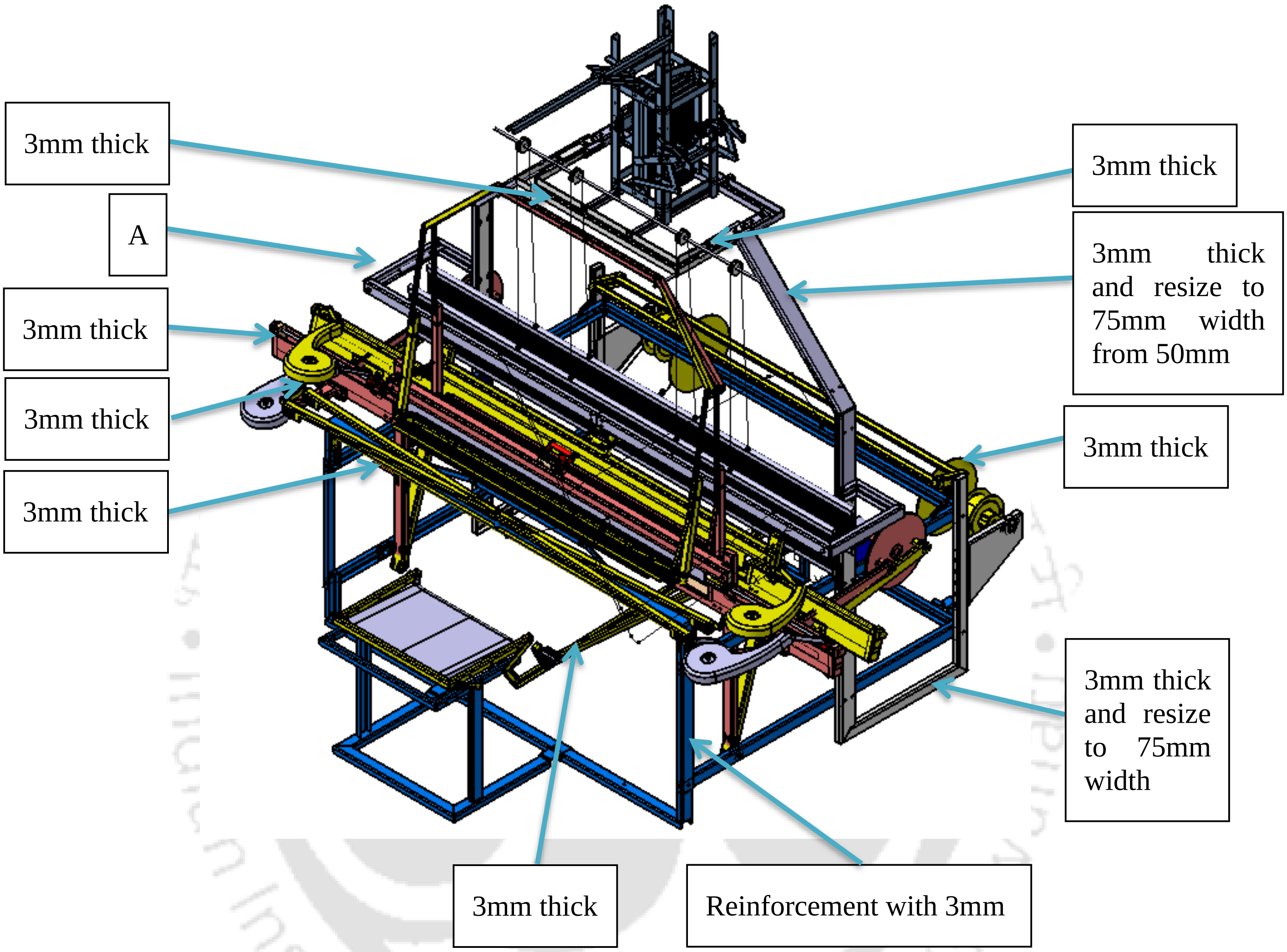


Figure 6.18: 3mm sheet thickness parts to avoid vibration of De-sign semi-automatic handloom

The treadle was initially made up of 2 mm twists in the paddle side due to clearance between the treadle bracket and pivot pin in the backside of the lower frame. Later, it is made with 3mm thickness, which works well.

Further, to strengthen the jacquard mounting, two more reinforcements were added, shown in Fig.6.18.

6.6 Oscillating backrest design

Oscillating backrest structure has not worked with sheet metal structure with 2mm and 3mm thickness in L or U shape. It bent with warp sheet pressure, as shown in Figure 6.21.

Figure 6.19: Sheet metal structured oscillating backrest

Sheet metal structure shown in Figure 6.18 have been reinforced with square bar as shown in Figure 6.20, still the bending problem exist with warp sheet pressure during shed formation of weaving.

Figure 6.20: Sheet metal structured with an additional square bar in the oscillating backrest

Figure 6.21: Sheet metal structured with reinforcement in the oscillating backrest

Figure 6.22: 1" square tube structured in the oscillating backrest

Square tube of a 1” in structure of oscillating bracket shown in Figure 6.22 sustained comfortably during weaving trial.

6.7 Complete metallic jacquard in sheet metal frame

The existing jacquards used a wooden frame with metallic mechanisms. It needs two types of material and requires two different types of professionals to execute the same. Wood wears out early, and fasteners loosen out during fastening with metal. Complete metallic jacquard in sheet metal frame shown in Figure 6.23 solve above problem also make it light weight.

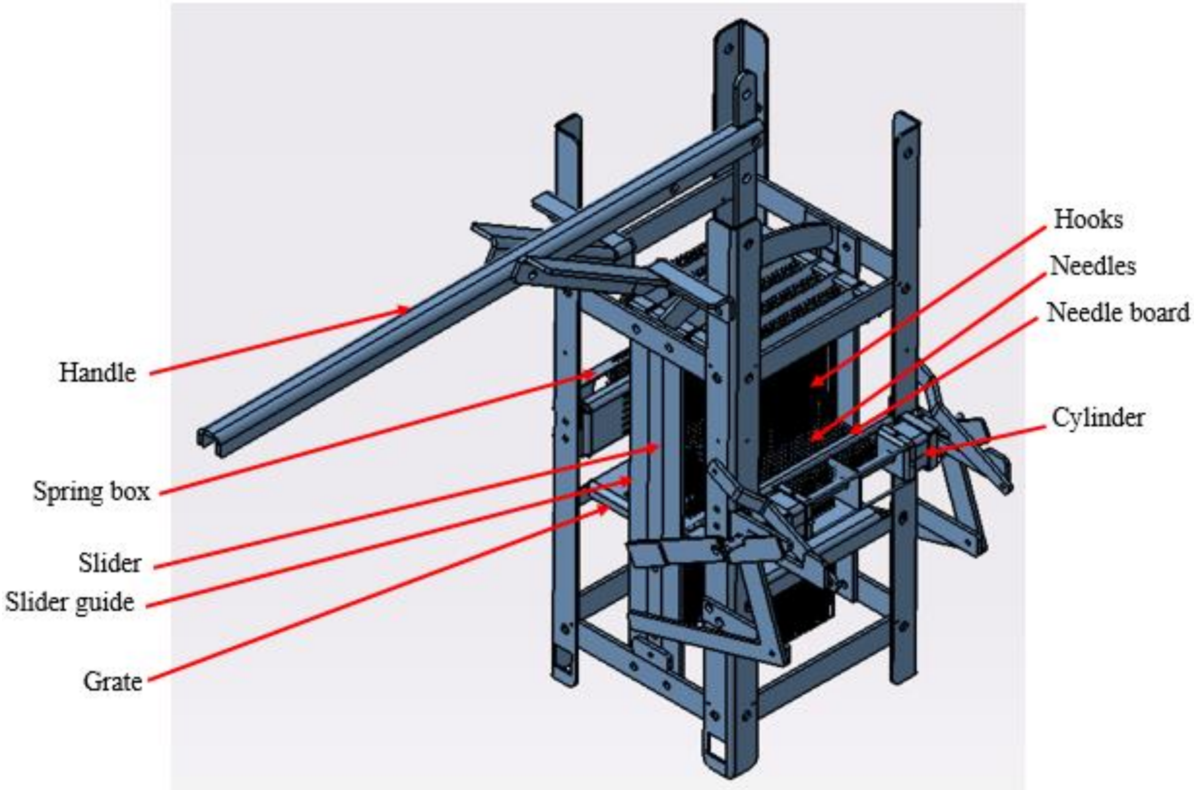


Figure 6.23: An improved jacquard over the traditional model

6.8 Complete metallic Winding wheel, Creel, and Warping drum

The winding wheel, Creel, and warping drum are made in the mild steel sheet metal to make the whole system in metal and to make every process in sync. Output from spinning wheel as the bobbin is input for ‘creel and warping drum combined system.’ Similarly, the output of ‘Creel and warping drum combined system’ is input as ‘warp beam’ for the handloom.

6.9 Supplier management

It is found that if manufacturer and supplier are different for raw material and operations like laser cutting, CNC bending, welding, and turning, the cost of manufacturing is less for individual operations but eventually increases the cost of material handling and supply chain management. Some operations like threading in holes may be missed in some parts when multiple manufacturers work as suppliers. Therefore, the number of manufacturers/suppliers must be less in the whole supply chain for smooth execution.

6.10 Damage of sheet metal part and product during transportation

As shown in Figures 6.24 and 6.25, individual sheet metal components/sub-assembly have been damaged during transportation. Some of the individual parts are assembled to make sub-assembly at supplier location to reduce the number of parts for transportation and reduce damage. The remaining parts are kept separately and were not assembled with any of the sub-assembly.

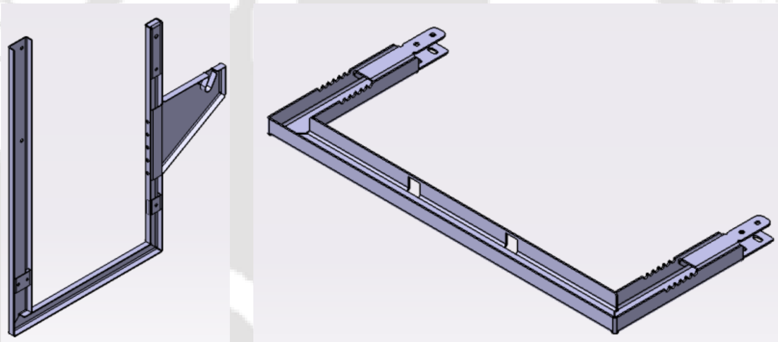


Figure 6.24: Examples of sub-assemblies of semi-automatic handloom

Figure 6.25: Damaged sheet metal component during transportation

The new packaging has been designed to avoid such damage, as below in Figures 6.26 to 6.29.

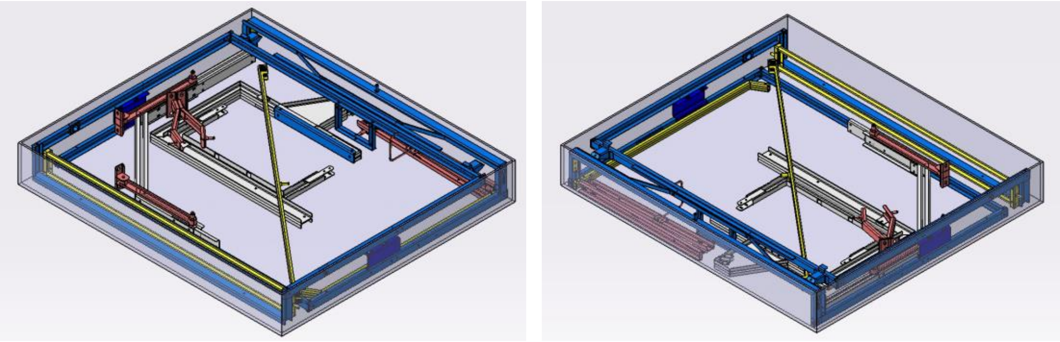


Figure 6.26: Package 1 of Semi-automatic handloom

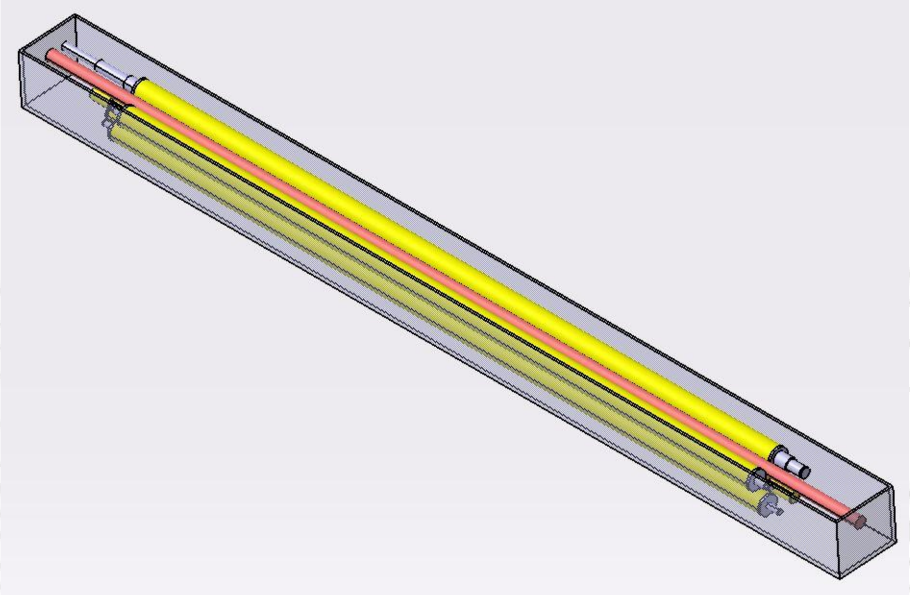


Figure 6.27: Package 2 of Semi-automatic handloom

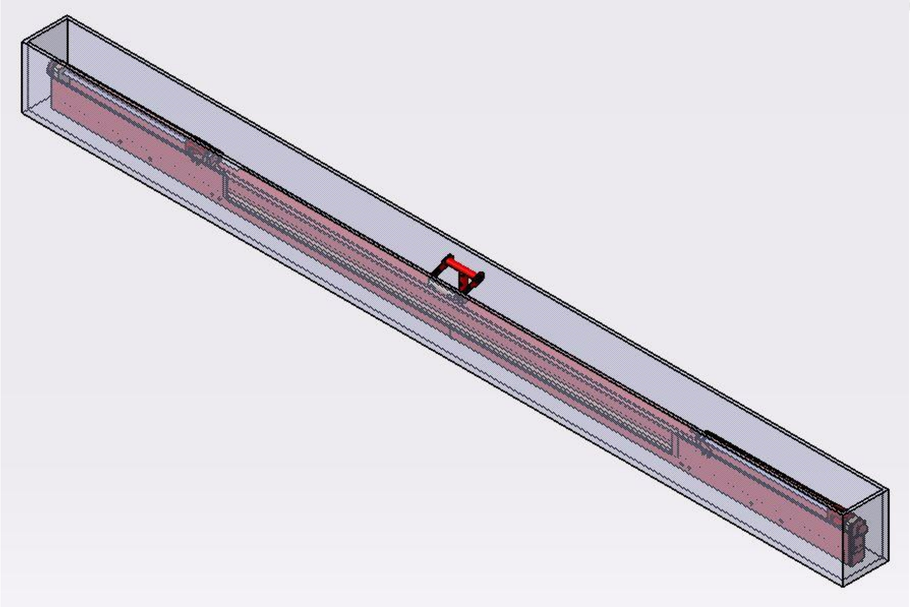


Figure 6.28: Package 3 of Semi-automatic handloom

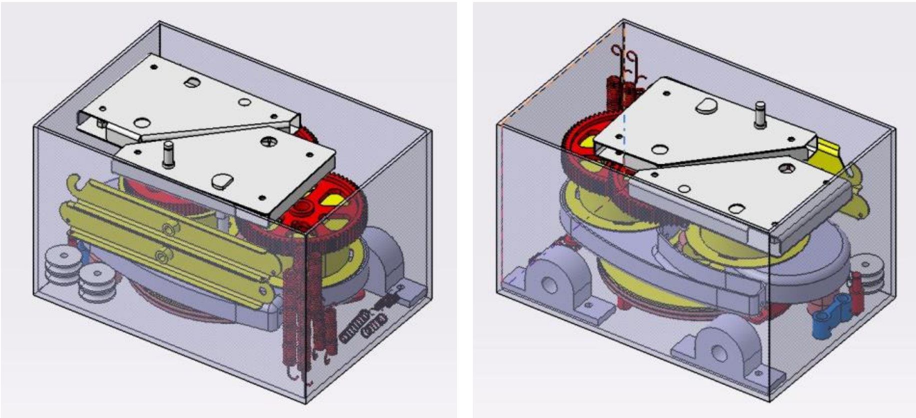


Figure 6.29: Package 4 of Semi-automatic handloom

The above four packages are for Semi-automatic handloom. Package 4 of the semi-automatic handloom can be fitted inside the structure of the seating system, as shown in Figure 6.29.

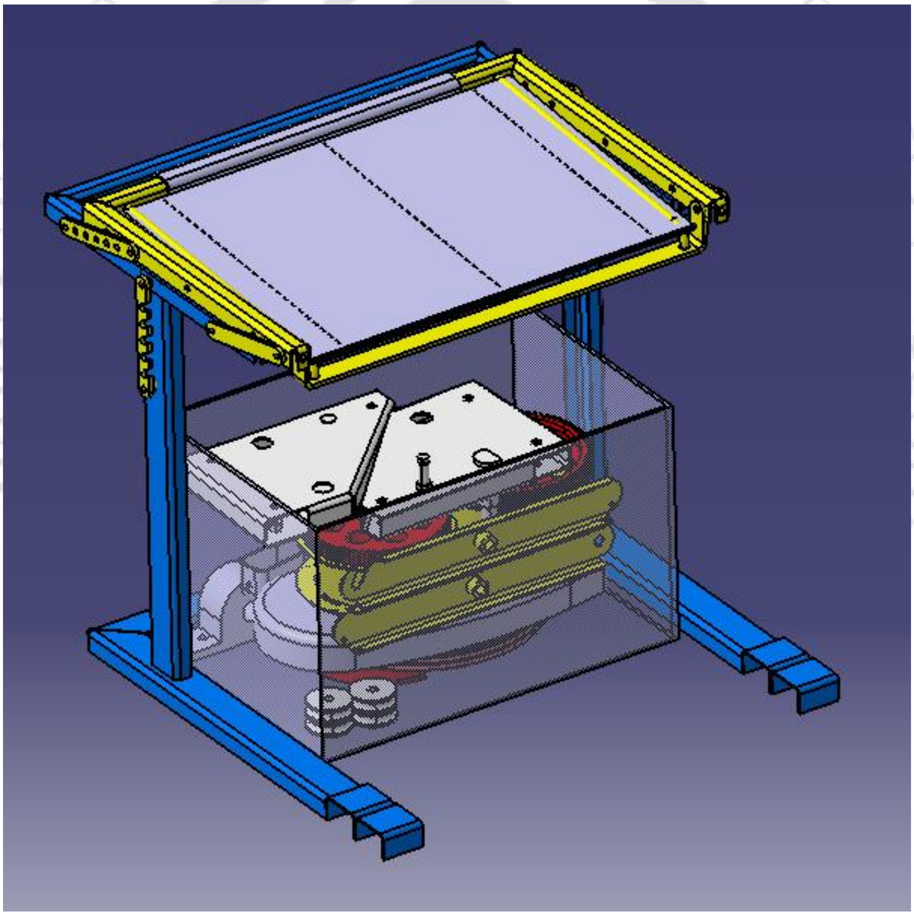


Figure 6.30: Package 4 within the structure of the seating system

Similarly, packages shown in Figures 6.31 and 6.32 are designed for warping drum and creel for warping as a pre-weaving process. Complete handloom with accessories packages are shown in Figure 6.33 to 6.35 for local transport or export through shipping container.

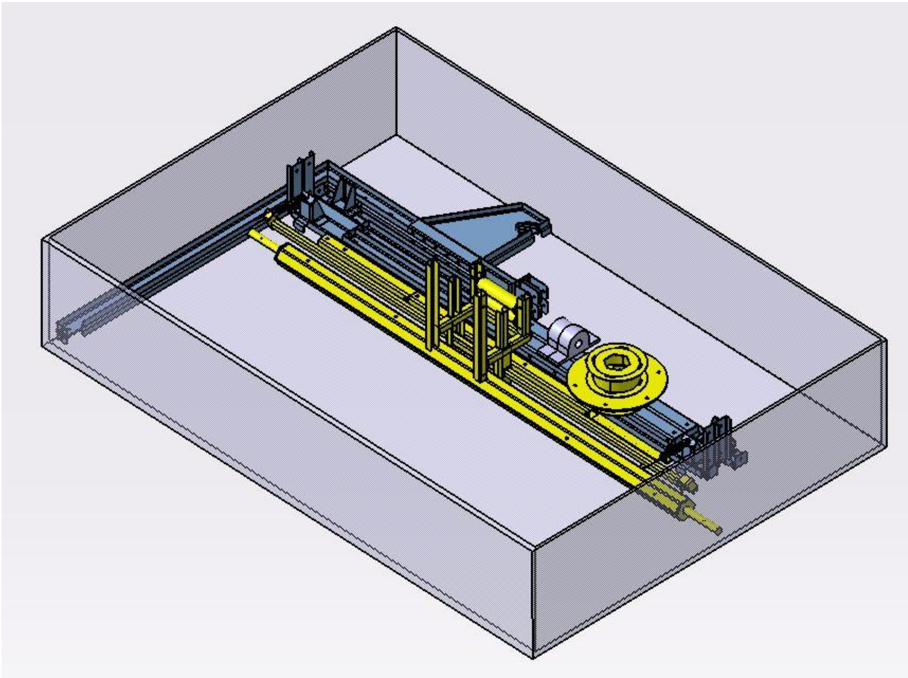


Figure 6.31: Package 5 of Warping drum

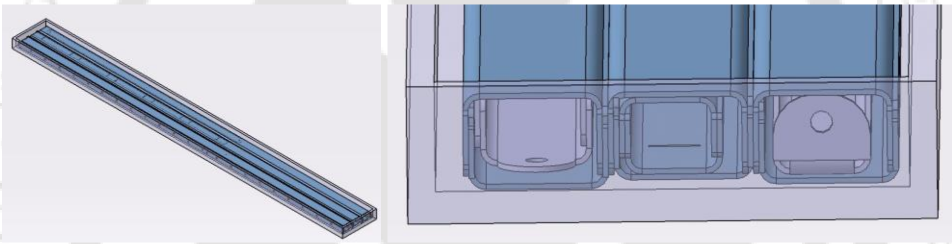


Figure 6.32: Package 6 of Creel

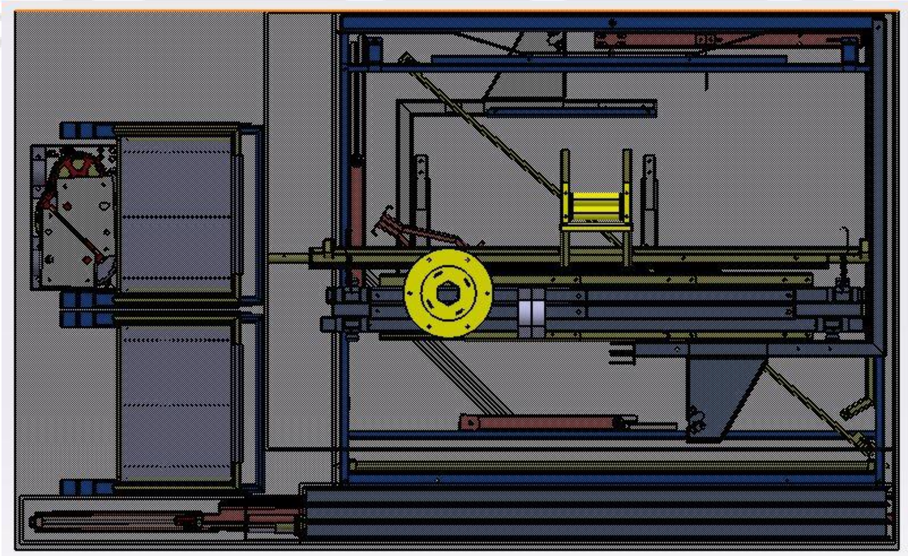


Figure 6.33: Top view of all packages of handloom set with vehicle (Tata 407)

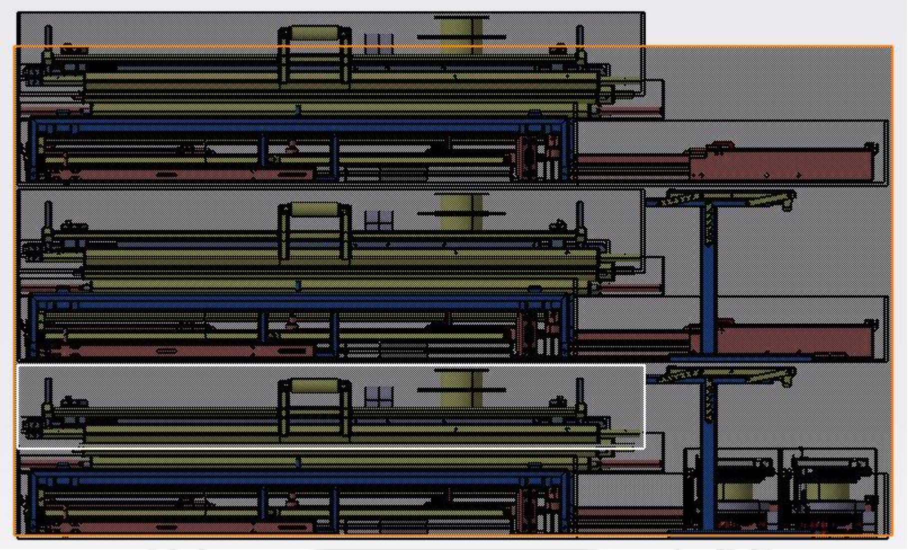


Figure 6.34: Front view of all packages of handloom set with vehicle (Tata 407)

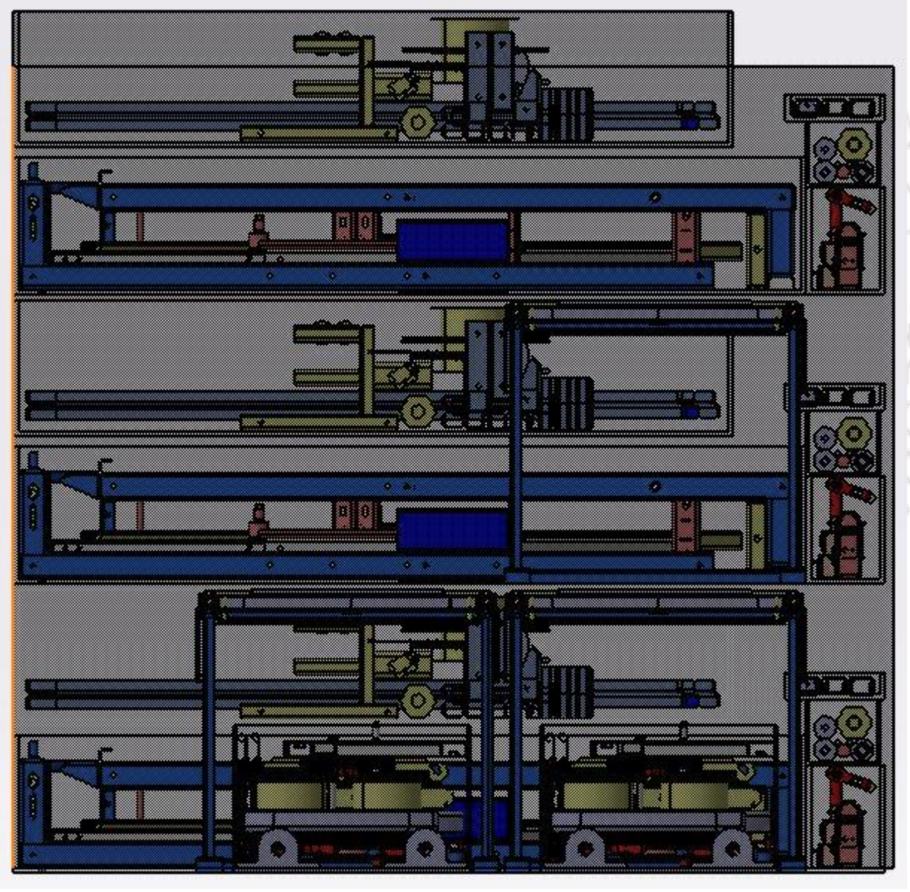


Figure 6.35: Side view of all packages of handloom set with vehicle (Tata 407)

The weight and size of these packages are as below Table 6.1.

Table 6.1: Package details of Semi-automatic handloom for transportation

Tool	Package no	Raw size (LxWxH)	Wt. in KG (253 total)
Semi-automatic handloom	**Package 1**	1750x1550x240	88
	Package 2	2020x140x125	32
	Package 3	2720x150x205	29
	Package 4	450x300x280	25
Warping drum	**Package 5**	1950x1350x260	54
Creel	**Package 6**	1850x190x60	25

Size (mm) of locally available vehicles are 2133 length x 1463 width x 1463 height for Tata ACE (Max weight 850KGS), 2743 length x 1676 width x 1524 height for Tata 407 (Max weight 2500KGS). Tata 407 vehicle can be used for transportation of all tools upto 3 sets (maximum 5 sets with cargo extension) in readily available cargo with 72% volume occupancy and using only 32% weight of its capacity, whereas Tata ACE can be used for transportation of warping drum and creel without semi-automatic handloom. All packages should touch the floor or base with their length and width to avoid buckling. Total space required for a handloom set (Semi-automatic handloom, warping drum and Creel) is 2600 length x 1650 width x 550 height with 72.4% volume occupancy. Separate packets are made considering weight for manual load unload. 20ft and 40ft containers are in regular use for export. Size (mm) and weight (KG) of 20ft and 40ft containers are 5900 x 2340 x 2290 with 21727 capacities (8 sets) excluding tare weight and 12000 x 2352 x 2295 with 26780 capacities (16 sets) excluding tare weight respectively.

6.11 Pilot testing

Handloom is tested by 11 expert weavers from government organizations as well as private weavers. These weavers were from ARTFED, Sualkuchi, and other part of Assam, as shown in Figure 6.35 to 6.39.

Figure 6.36: Trial by weavers from Sualkuchi, Assam

Figure 6.37: Trial by Research scholar and Technical staff of IIT Guwahati

Figure 6.38: Trial by ARTFED Assam

Figure 6.39: Trial by weavers from various areas of Assam

Figure 6.40: Trial at Handloom research and development centre, Ambari, Guwahati

6.12 Customer visit

Customers from the Department of Handloom, Handloom research and development centre, ARTFED, and UNDP have seen the prototype and shown interest in this semi-automatic handloom, as shown in Figure 6.41 to 6.43.

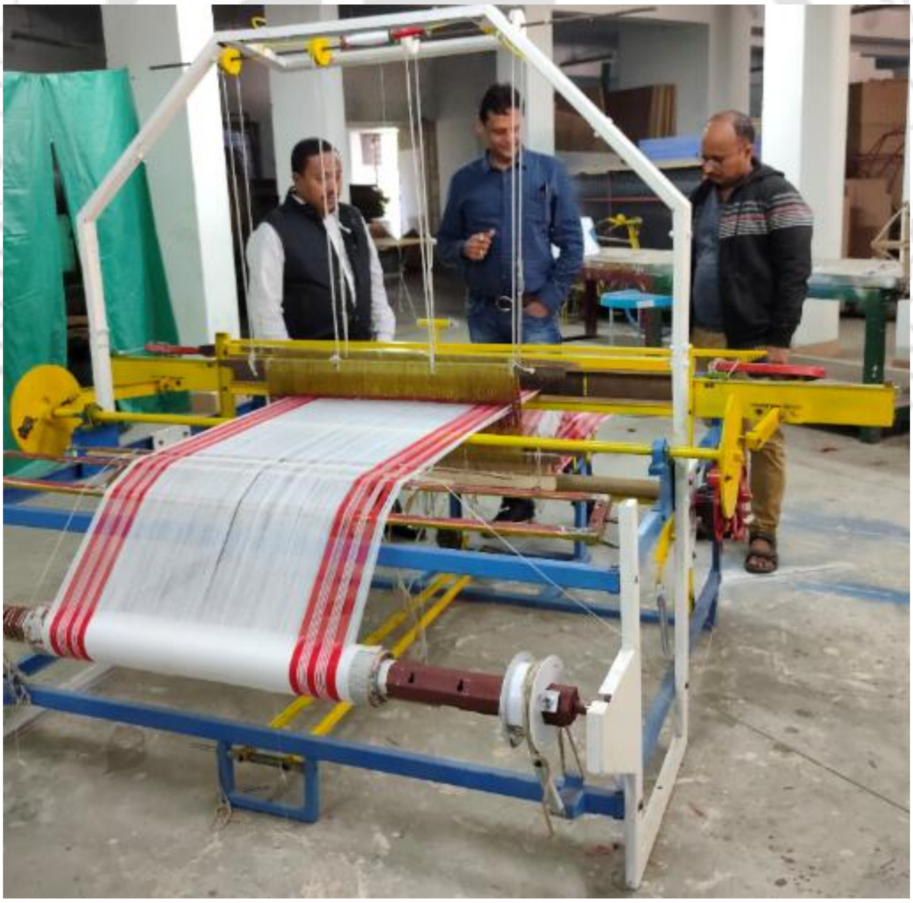


Figure 6.41: Customer visit at Guwahati workshop

Figure 6.42: Customer visit at Guwahati workshop

Figure 6.43: Customer visit at Guwahati workshop

6.13 Semi-automatic handloom in use for weaving at customer location

More than 115 sets of semi-automatic handlooms have been bought by the Department of handloom, master weavers, and weavers from Assam, India. Installed semi-automatic handloom shown in Figure 6.44 to 6.49 at weaver's location.

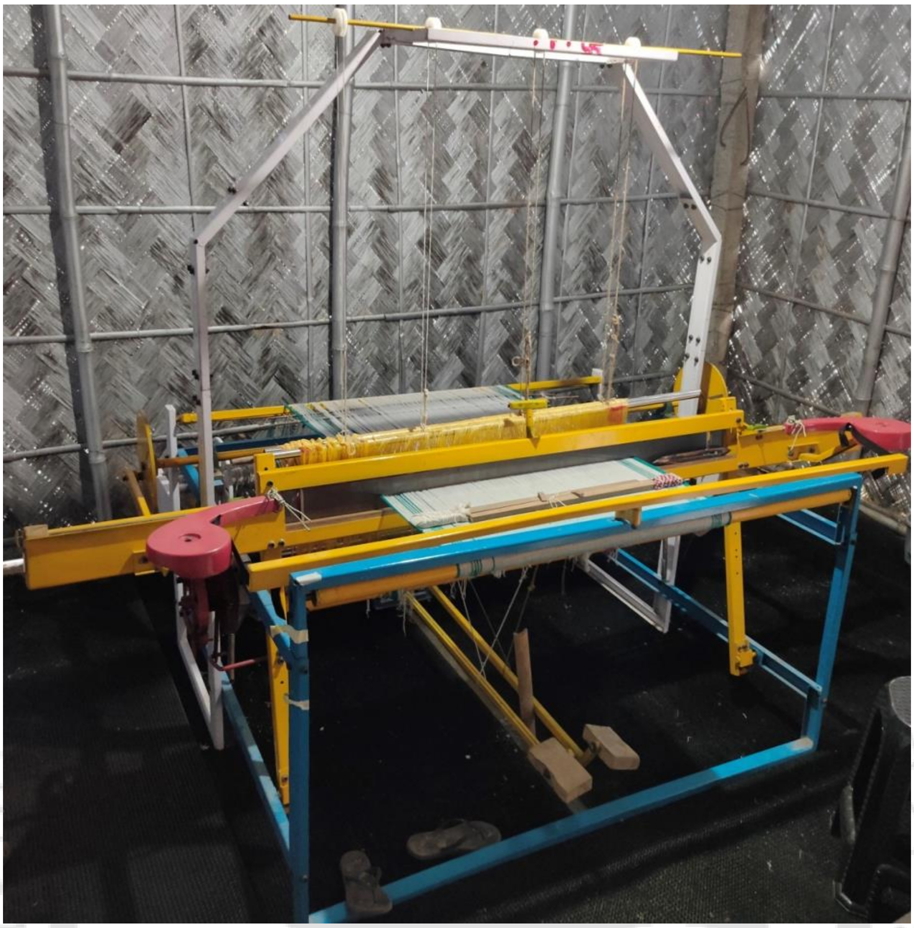


Figure 6.44: De-sign semi-automatic handloom without jacquard at customer location

Figure 6.45: Semi-automatic handloom on production

Figure 6.46: warping drum with creel at customer location

Figure 6.47: Semi-automatic handloom on production on another site

Figure 6.48: Semi-automatic handloom on production on another site

Figure 6.49: Semi-automatic handloom for distribution

It is found that weavers need training for a few days before weaving to acquaint themselves with the semi-automation part of the semi-automatic handloom.

One weaver can weave three towels of 5 feet in length each in a 8 hours working day. So, the weaver can weave at 2 feet/hour.

6.14 Production consumption cycle

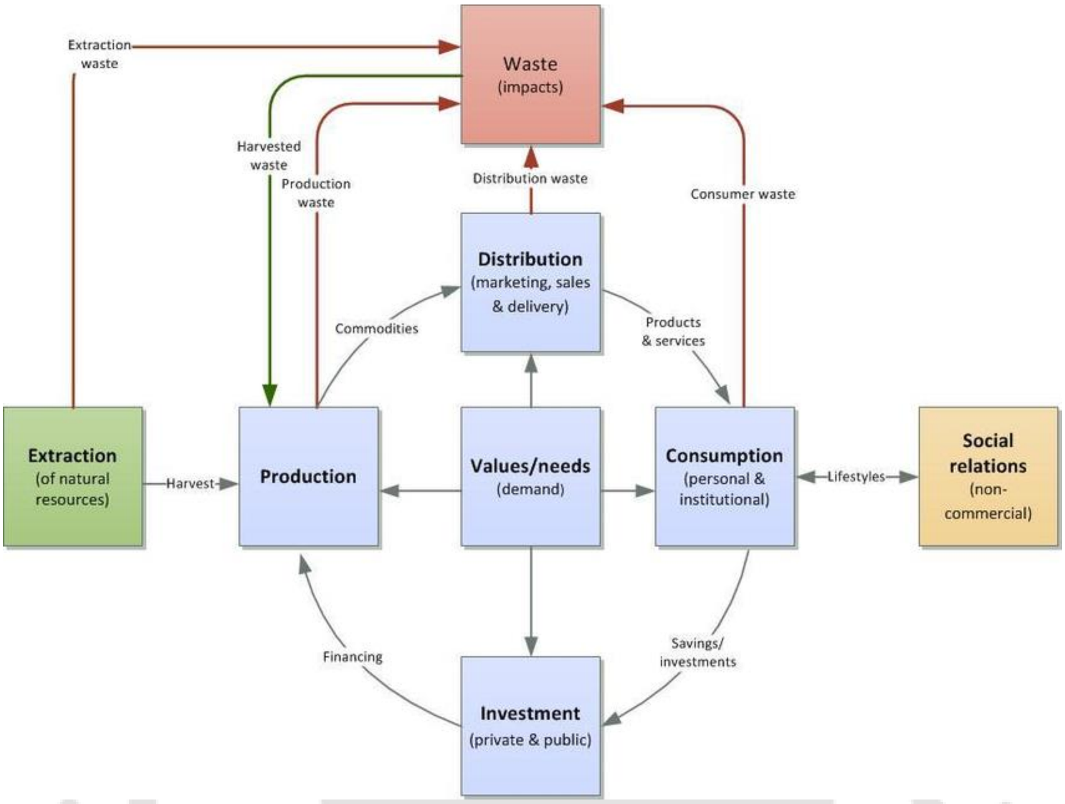


Figure 6.50 Production consumption cycle

Sustainable consumption and production shown in Figure 6.50 refer to "the use of services and related products, which respond to basic needs and bring a better quality of life while minimizing the use of natural resources and toxic materials as well as the emissions of waste and pollutants over the life cycle of the service or product.

Parameters to check production like Meters per Day for production capacity, Meters per hour for efficiency, and Hours per product for the overall delivery time have been considered to evaluate after trial. Customer demand, materials, equipment, workforce, processes, and controls are the six principles that have been considered during the design of the new Fly shuttle semi-automatic handloom. Design concept considered for transportation of the loom in knocked down state with small and medium utility vehicles available in the rural and urban area. All large-size structural members of the loom structure have been designed for disassembled to a smaller size to facilitate compact packaging. It will help in distribution over different geographic locations. Also, it is considered to design the handloom for easy maintenance and weaver's safety by providing the loom with safety guards as many mechanisms rotate and move during weaving. Human factors have been given an utmost focus to improve convenience in use like seat and sley handle design and treadle design. It will be more durable as it is made of steel over wood.

All wearable parts are identified and designed so that replacement will be easy. Master datum is identified in assembly and part level; accordingly, tolerance/fit is chosen for the smooth function of the loom.

Chapter 7: Conclusions and Future work

Every motion has been analyzed through the various alternatives available with their advantage and disadvantage in choosing the right fit for the new semi-automatic handloom. Existing handloom and semi-automatic loom were studied with the mechanism of each motion. Also, it has been checked for its ornamentation capability smoothly as and when required. Productivity has been improved by 50%, but the durability and mass manufacturability improved significantly through ease of processing by laser cutting and CNC bending. Shanti loom has been considered a reference loom to choose as it was a commercially successful model and physically available nearby. Mild steel sheet metal C frame structure is used for making the frame of the semi-automatic handloom. Shedding and beat-up motion have been improved handling through an adjustable seating system, treadle, and beat-up handle. Picking has been eliminated through the Burmese picking mechanism. It directly reduces the shoulder pain of the weavers. Maximum part/sub-assembly size is considered based on locally available cargo vehicles.

All parts are easy to fit during transportation. Also, it is easy to assemble and disassemble. Accessories like spinning wheel, Creel and warping drum, seating system, and jacquard are designed to synchronize input, process, and output properly. Weavers have trials from Sualkuchi, Guwahati, ARTFED, Handloom development and research centre etc. Many customers have visited to see the loom and well-functioning in customer-location. Picks per minute are 45 in the new semi-automatic handloom against 30 picks per minute in the traditional handloom. So, productivity improves by 50% in this semi-automatic handloom compared to traditional handloom with ornamentation capability.

7.1 Concluding remarks against Research questions

Validation of the research questions (RQ) have been given below.

A1: Is warping productivity essential to enhance the weaving productivity of a loom?

Answer: It was observed that weaving has pre-weaving and weaving process, however in most of the handloom development initiative pre-weaving processes were taken for granted. Therefore, this research question was formulated to understand the contribution of pre-weaving process like warping, looming etc. in weaving cycle. Since, this research question was formulated and the weaving process was considered holistically, a new portable metal warping drum was designed. Based on the finding from the research that warping is a very important process that can contribute to the enhancement of productivity of handloom. This is because for continuous weaving and improvement in quality of the woven cloth. Warp sheet should be free from any variation from warp tension between the warp threads, all warps parallel to each other and free from entanglement. In traditional process of warping, this cannot be achieved. Warping was done by extending the warp yarn in the open field for warping directly from the hank without winding of individual yarn. This way, maximum 15-20 meters' length was possible to warp in a single warp beam. Spacing between warp yarns is not uniform. Controlling the width of the warp in warp beam for specific cloth width was a time-consuming activity. To improve weaving productivity, pre-weaving, weaving, and post-weaving processes must be improved. The cycle time of all these activities should be in tune with each other to avoid idle time or extra inventory buildup. It is known that the output of pre weaving process is the input for weaving. Both should be designed in synchronization for proper fitment and smooth operation. Warping is an essential pre-weaving process that directly impacts weaving. Existing warping machines were designed in wood, considering the traditional handloom machinery. It was necessary to build a new metallic warping machine with Creel, which accommodates the warp beam like the new weaving loom. The new warping machine can warp about 45-50 meters in a single warp beam. This saves time for eliminating 2/3rd of setting time for looming if sectional warping is used instead of traditional weaving process. It was observed that it takes on and average two days for looming a warp based on end per inch and width of the warp. Thus using sectional warping machine to prepare warp sheets having 3 times the length of warp prepared using traditional process results in saving of 4 days, which can be used for weaving fabric.

Also every time a warp is used in a loom on and average 1.5 meter of warp sheet is wasted at the beginning and end part of the warp used for knotting on to the cloth beam and at the end of the warp sheet, it is not possible to weave to the last part since shedding, picking, beat-up is not possible to the point. Therefore, 3 meters of additional fabric can be gained by using sectional warping machine with 3 times longer warp compared to traditional warping machine.

B1: How can the working efficiency of a handloom be enhanced?

Answer: It was observed that weaving productivity enhancement have limited scope in handloom as it is operated by hand. We can improve comfort ergonomically during weaving to increase productivity indirectly. Weaving consists of three primary motions: shedding, picking, and beat-up. A few secondary motions are take-up and let-off. Also, many other tertiary motions like temple motion, oscillating backrest etc. exist to support weaving.

Shedding was done with the bamboo treadle. Bamboo treadles were slippery when applying force through the leg to create a shed. Introducing a new foot paddle at an appropriate distance from the seating system is crucial to improving efficiency. Shed formation needs little looseness in warp yarns, and the warp yarn should be tightened during beat-up to make quality fabric. The oscillating backrest helps to loosen and tighten the warp with the help of springs.

In the existing setup, manual picking causes shoulder and wrist pain. Also, picking was done through one hand only by pulling as the other hand was engaged to make the beat-up motion, which causes one side musculoskeletal disorder. In the new loom, this motion is automated with beat-up motion with the help of the Burmese type of picking mechanism. Sley pivot is on the bottom side of the frame of the loom.

Beat-up was done manually earlier, so weft yarn pulled by sley to newly made fabric with irregular force every time. Every time a new yarn is attached to the fabric, the distance between sley and beat-up distance is reduced. Shed formation is also irregular due to this reason. These problems exist due to manual let-off and take-up mechanisms, which need to be winded up and adjusted every 15-20 minutes of weaving. In the new beat-up mechanism, the beat-up location to sley distance is fixed as it is connected with crank and flywheel. This mechanism also helps automate take-up and let-off motion through an improved 5-wheel gear mechanism with two shafts. Earlier, three shafts were used to make a 5-wheel gear mechanism, which also need gear change or lever change for adjustment of pick spacing.

Take-up was done earlier in the wooden beam. Sometimes it slips, and warp tension reduces, which needs to be adjusted regularly. Also it is observed that existing take-up mechanism requires 5-8 minutes of adjustment time after weaving 3-4 inches of fabric, which is eliminated completely with the current take-up. In the current take-up mechanism, an emery-wrapped wheel is used to avoid slippage. Also, the gear mechanism has a provision to disengage the automation during ornamentation. When the ratchet wheel comes forward with driving pawl movement through bend rod of oscillation of sley, the pick-up ratchet wheel slides over the take up guard and in the reversing motion pulls forward the ratchet wheel with locking pawl as per the setting of the pick spacing. Adjustment of pick spacing is possible through the lever mounted on the stud pin and is secured to it with nuts and bolts. This holds the take-up guard in fixed position.

Let off mechanism was manually done by rotating the warp beam and maintaining the warp tension through a set of ropes. One stick was used for the initial fixing of warp yarn in the warp beam for warping as it was a plain wooden beam. The wooden beam was not precisely round as it was manually made, causing an uneven warp flow. Currently, it is done through spring in synchronization with take-up motion to release the warp to a distance equal to the diameter of the weft yarn every time picking takes place. A regular hexagon beam is used in the new design to get an even flow of warp, and a unique cutout is provided in the hexagonal warp beam to locate and fix the knot for a set of warp yarn. It has been taken maximum care in fitment to avoid runout and concentricity.

Width control of the woven fabric was done through wooden temples with hooks, which causes uneven fabric width. A specially designed holder for temple motion helps control the fabric's width. The backrest plays a crucial role in weaving for warp positioning. In the traditional loom, it is just a round beam. An oscillating backrest is a rectangular fabricated structure with a spring connected with the loom's frame. It has two pivot pins to rotate and adjust as required with or without a shed.

The earlier stool/bench type of seating arrangement was used to sit for weaving, i.e., executing primary motions like shedding, picking, and beat-up. It causes improper distance between the hand and leg of the weaver to beat-up handle and treadle, respectively. These can be overcome by a newly designed seating system that is adjustable simultaneously horizontally and vertically.

Weaving was interrupted regularly for various secondary motion activities. Working efficiency can improve if major primary and secondary motions can be automated through synchronization. It means one manual motion leads to multiple automatic motions, making it a semi-automatic handloom without affecting the ornamentation capability of the handloom. Also, the ergonomic and operational improvements may improve the working efficiency drastically. These design interventions help improve loom productivity with better human factor consideration, aesthetically pleasing form, affordable, easy to manufacture, and use.

B2: What factors contribute to the enhanced quality of the woven fabric?

Answer: Pre-weaving process such as warping provides longer warp sheet with equal spacing and entangle free warp yarn as input material improve quality of weaving. In traditional method, additional force was required to form shed with every picking as beat-up oscillating width reduce continuously. To improve quality, the controlled shedding motion with the spring-loaded oscillating backrest reduces the warp or weft breakage. Manual picking was done through irregular force by hand may cause the shuttle out of the sley race and break the yarn. Automated Burmese type of picking mechanism and beat up motion in synchronization with sley connecting the flywheel with crankshaft helps uniform picking to improve the fabric defects. Spacing between picks will be uniform due to this mechanism with uniform beat-up. Automatic take-up and let-off motion help uniform continuous weaving. Oscillating backrest ensures optimum tension of warp. It should be loose enough to create space to pass the shuttle in the sley race and tension to avoid warp breakage. Temple motion ensures the uniform width of the fabric without making pin mark in the fabric.

B3: How can value addition be achieved in a loom?

Answer: A handloom weaver cannot compete with a power loom or high-tech looms by plain weaving handloom product which cost very less in the market. Handloom can make a unique design through ornamentation, which is impossible in other types of looms. Therefore, Handloom weavers focus on using their expertise to weave tailor-made products. Few weavers are earning more than 1 Lacs rupees by doing the tailor-made weaving for the occasional dress. The whole set of pre-weaving accessories like warping drum and creel are also designed with a semi-automatic handloom for a smooth flow from input to output through the appropriate process. Jacquard is also developed full metallic to fit the loom with additional durability. We can do regular weaving, and whenever interruption is required for ornamentation can be stopped from doing the same. Lead time to weave any fabric will shrink due to implemented design intervention in the traditional handloom. Sley pivot is under the frame, causing the light structure of the semi-automatic handloom. Nesting is done for significant sheet metal parts to improve the efficient use of material. It has been taken utmost care to connect small parts with very small joinery to avoid misplacement under the cutting machine bed of small laser-cut sheet metal parts after cutting. Sub-assembly is designed for easy transportation, assembly, disassembly, and maintenance. Efficient material utilization, reduced lead time to weave, easy assembly and disassembly are notable value additions to the new semi-automatic handloom.

Economic feasibility was studied concerning the cost of existing handloom and the approved cost of handloom for the subsidy by the Government of India. Research also considered the cost-benefit of the product. The technical and economic feasibility of the semi-automatic loom has been found acceptable.

Traditional handlooms have separate designed handloom for plain weaving and ornamented weaving such as dobby or jacquard handloom whereas our modular handloom can be converted from plain to ornamented weaving by replacing only two brackets and adding few additional brackets. Also our handloom can weave both cotton and silk, which lacks traditional handloom.

B4: What type of ergonomic intervention is essential to enhance productivity without higher physical exhaustion?

Answer: It is known that weaving consists of three primary motions, i.e., shedding, picking, and beat-up. Weaving involves many motions to execute in rhythm and causes dynamic repeatable/cyclic movement of body parts of the weaver. Shedding is tedious if the seating system is fixed. In general, a stool is used to sit and operate the handloom. It starts with sitting level to leg position to operate the paddle in the treadle within 15-degree comfortable movement. It needs an adjustable seating system in the horizontal and vertical directions. A fixed round bar to foot paddle is another ergonomic intervention to improve leg comfort. Distance of Hand palm with sley handle is within the acceptable limit in the horizontal and vertical direction. Compared to a rigid handle, a flexible handle will improve wrist comfort. The force required to pull the sley and paddling of the treadle is measured to check the permissible limit.

Picking is automated, so one operation eliminated causes lower physical effort.

Beat-up motion is manual, but its movement reciprocates with the flywheel, causing easy movement of sley. In the case of automated beat-up motion, it is tough to stop weaving during ornamentation in the required position. Therefore, we have kept the beat-up motion manual even though we could have automated the same.

Take-up and let-off motions are also automated, so no intermediate interruption is required to adjust the beam frequently to maintain tension in the warp yarns. Sometimes, the gear was disengaged in the 5-wheel gear mechanism due to improper distance between shafts or fitted the shaft with inclination in the loom frame. Rearrangements of the gears were done to fit these in two shafts to avoid the disengage issue. Additional stops have been provided to stop the automatic take-up and let-off during ornamentation.

C1: What are the shortcomings of wooden frame looms?

Answer: Introducing semi-automatic mechanisms and specifications like smoothness, precision, standard, durability, and ease of mass manufacture requires limited usage of wood as a material. Wooden structure will require regular maintenance and causes limited commercial application. In 1995, tree felling is banned in Assam, therefore it is very difficult to get quality timber in Assam and many other parts of India as well. Low quality timber deforms and does not provide required geometry required for the required function. Wooden structures have been avoided due to the unavailability of quality wood material and the shortage of skilled carpenters for fabrication. Against this, metal fabricators are readily available cheaply in urban and rural areas. It can also protect the environment by avoiding wood material. Mass manufacturing of handlooms was not possible with wooden handlooms. Piece-to-piece location in wood requires great attention and time over a steel structure. Also, wood lacks standardization to replace parts during maintenance. Currently, broken parts are measured and manufactured as parts are not identical between handlooms.

C2: Can the handloom-making process be changed to achieve a better product and process?

Answer: During the field and product study, it was found that few metal structured handloom were introduced in the market including Shanti loom discussed in literature. These handlooms are costly but also lacks adequate quality. These looms used standard profiles like angles, flats, square, round and rectangular tubular section, however for precision these required significant numbers of jigs and fixtures for drilling, milling, welding etc. Any product takes more time to manufacture; if we design a product, which can be manufactured with special material, it needs a special process to manufacture and a skilled workforce to process the same, resulting in a high cost of the end product.

Therefore, to arrive a better product and process with alternative material and process, conceptualization was done to use state of the art manufacturing process such as laser cutting, CNC bending, CNC turning and milling etc. Therefore, it has been taken utmost care to use readily available processes limited to laser cutting, CNC bending, welding, turning, fitting, and powder coating of mild steel parts for corrosion protection. Casting and milling are done rarely. Mild steel is used as a material. Round (Turned) parts are designed in such a way that any fabrication shop and mini tool room can manufacture them. Small laser-cut parts are joined together for laser cutting with minor joints to avoid misplacement in the debris below the machine bed as shown in figure 4.82 to 4.85. The maximum size of these parts and sub-assemblies are designed considering transportation of the handloom in the small to medium utility vehicles used in rural and urban areas. The hole size is kept optimum for assembly and disassembly of parts and products without affecting its function. Steel structured loom will be more durable than a wooden loom. Still, few parts are produced in wood such as sley race and picker stopper, but these will be developed through aluminum extrusion in the future. There are many bought-out items like the bi-cycle paddle used for shedding, shuttle, picker, reed, heald, pulley, pirn etc. to facilitate easy availability from the market. Good machine design is always designed to have minimum make parts and maximum bought-out items. Therefore, the new commercially suitable handloom is designed by considering primarily design for adequate duration services, design for convenience in use, design for packaging, and design for maintenance.

7.2 Research and design contributions

This research has provided a few guidelines to design and to manufacture handloom for the comfort of the weaver, faster weaving with ornamentation, and improved durability.

It is a noble step to get the Burmese picking motion with the sley pivot on the bottom side, which will eliminate the shoulder pain of the weaver. The part and sub-assembly are easy to transport. This research is an initiative as design Intervention and an interface between material of traditional handloom and newly designed handloom developed with wood and steel, respectively. There is plenty of opportunity in the product considering the handloom cluster development in India. The result established that the newly designed handloom is more productive with enhanced productivity, better Human factor consideration, and aesthetically pleasing form; much more affordable, easy to manufacture, and easy to use. In the future, the Laser cutting process of sheet metal and computerized bending is preferred to avoid tool room machines like milling and drilling. It can also substantially improve the quality and productivity of handloom manufacturing. The new design will also incorporate the various new parts added in the handloom to achieve automation during weaving, which was tough in traditional wooden handloom. Also, an adjustable seating system is designed to improve shedding and beat-up motion. The newly designed seating system is subjected to many variations due to treadle movement, sley movement, with leg and hand movement. Also, the variation in body dimensions was considered to accommodate the majority of weavers. This seating system will help all weavers who work for long hours with a semi-automatic handloom that works at 45 picks per minute compared to 30 picks per minute of a traditional handloom. Our finding suggests that a minimum of 3mm mild steel sheet thickness is needed for the structure of the seating system, and 5mm mild steel sheet thickness is needed for linkage parts. 2mm mild steel sheet thickness seating system is not strong enough to bear load during weaving.

7.3 Future work

1) Multiple shuttle boxes are for check/pattern weave. The first automatic shuttle change machine was developed in 1835 to insert yarns of a different colors.
2) Multiple weft use. Automatic pirn (weft supply) change was first invented in 1895 by J. H. Northrop. This technology became commercially viable only after 1950.

3) Twill weaving
4) Automatic shedding in regular weaving without ornamentation as a modular attachment
5) An interface utilizing app or website development for customized fabric design selection of various elements in a garment as customer input then those requirements will be given to weavers for weaving fabric
6) Further improvement to make it a personalized loom for customized weaving
7) Shuttle design intervention to increase pirn change interval

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Appendix 1

Item No	Mtl.	Overall size	Item	Qty	Wt./piece (Kg)	Total Wt.	Remark	Detail Page No	SA Page No
1	MS	2x87x1765	Lower Frame Rear Member	1	2.344	2.344	Lasercut	49/50	12
1.1	MS	2x131x141	Let off Spring Bracket	2	0.194	0.388	Lasercut	51	12
1.2	MS	2x66x587	Treadle Bracket	1	0.518	0.518	Lasercut	52	12
2	MS	2x91x1368	Lower Frame Right Member	1	1.884	1.884	Lasercut	53/54	13
2.1/3.1	MS	2x60x69	Bracket_Sley Sword Bearing Housing L/R	2	0.044	0.088	Lasercut	55	13/14
3	MS	2x91x1368	Lower Frame Left Member	1	1.884	1.884	Lasercut	56/57	14
4	MS	2x87x2064	Lower Frame Front Member	1	2.896	2.896	Lasercut	58/59	
5	MS	2x87x1765	Upper Frame Rear Member	1	2.351	2.351	Lasercut	60	
6	MS	2x91x1368	Upper Frame Left Member	1	1.863	1.863	Lasercut	61/62	15
6.1/7.1	MS	2x75x185	Upper Frame Insert Member L/R (for ?)	2	0.212	0.424	Lasercut	63	15/16
7	MS	2x91x1368	Upper Frame Right Member	1	1.863	1.863	Lasercut	64/65	16
8	MS	3x86x2118	Upper Frame Front Member	1	2.644	4.046	Lasercut	66/67	17
8.1	MS	D20x48	Upper Frame Front Member Pin for Picking Arm	1	0.048	0.048	Round	131	17
9	MS	3x113x2400	Cross Frame Lower Right Member	1	5.424	5.424	Lasercut	70	18
11.1/9.1	MS	2x50x69	Cross Frame Lower Insert Member	8	0.05	0.4	Lasercut	69	18/19/20
11.1/9.1	MS	2x50x69	Cross Frame Lower Insert Member	8	0.05	0.4	Lasercut	b	18/19/20
10	MS	3x113x2400	Cross Frame Lower Left Member	1	5.424	5.424	Lasercut	70	19
11	MS	3x113x1414	Cross Frame Upper Left/Right Member	2	3.754	7.508	Lasercut	71	20
12	MS	2x91x452	Cross Frame Central Member	1	0.652	0.652	Lasercut	72	21
12.1/9.1	MS	3x101x300	Cross Frame Insert Member	3	0.701	2.103	Lasercut	73	18/19/21
13	MS	2x91x1350	Cross Frame Pulley Support Bracket	1	1.726	1.726	Lasercut	74	
14	MS	2x91x850	Sley Sword Left/Right	2	1.178	2.356	Lasercut	75	22
14.1	MS	2x60x69	Sley Sword Insert Bracket_	2	0.06	0.12	Lasercut	76	22

			Left/Right						
14.2	MS	D6x304	Take Up Actuating Lever	1	0.068	0.068	Round	132	22
15	MS	2x71x100	Footstep Bracket Left/Right Rear	2	0.105	0.21	Lasercut	77	23
15.1	MS	2x40x71	Footstep Bracket Left/Right Front	2	0.042	0.084	Lasercut	78	23
15.2	MS	D20x100	FootStep Pin L/R	2	0.149	0.298	Round	133	23
16	MS	2x182x185	Main Shaft Bearing Bracket Right	1	0.519	0.519	Lasercut	79	
17	MS	2x182x185	Main Shaft Bearing Bracket Left	1	0.519	0.519	Lasercut	80	
18	MS	2x69x177	Insert for Gear Bracket_Upper Frame L/R Member 6/7	2	0.184	0.368	Lasercut	81	15/16
19	MS	2x222x293	Emery Roller Bracket Outer_Right Part A	1	0.734	0.734	Lasercut	82	24
19.1	MS	D20x65	Cloth Roller Bracket Pin_L/R Part B	2	0.103	0.206	Round	134	24/25
20	MS	2x177x250	Emery Roller Bracket Inner_Right PartA	2	0.522	1.044	Lasercut	83	26/27
20.1	MS	D30x165	Intermediate Compound Wheel Shaft Part B	1	0.329	0.329	Round	135	26
21	MS	2x68x90	Front Roller Bracket	2	0.093	0.186	Lasercut	84	
22	MS	2x69x199	Rear Post Oscillating Back Rest Bracket L/R	2	0.201	0.402	Lasercut	85	18/19
23	MS	2x73x498	Crank Arm Left/Right	2	0.54	1.08	Lasercut	86	28
23.1	MS	D38x29	Crank Arm Bearing Bracket A Left/Right	4	0.093	0.372	Round	136	13/14/28
23.2	MS	D38x29	Crank Arm Bearing Bracket B Left/Right	4	0.091	0.364	Round	136	28
24	MS	2x73x354	Cloth Roller Bracket Left	1	0.368	0.368	Lasercut	87	29
24.1		D30x20	Cloth Roller Bracket Insert L/R	2	0.047	0.094	Round	137	29/30
25	MS	2x73x354	Cloth Roller Bracket Right	1	0.376	0.376	Lasercut	88	30
26	MS	2x73x140	Crank Arm_Sley	2	0.156	0.312	Lasercut	89	31/32

			Connecting Bracket L/R Part A						
26.1	MS	2x46x60	Crank Arm_Sley Connecting Bracket L/R Part B	2	0.039	0.078	Lasercut	90	31/32
26.2	MS	2x46x60	Crank Arm_Sley Connecting Bracket L/R Part C	2	0.038	0.076	Lasercut	90	31/32
27	MS	2x73x140	Picking Cam_Sley Connecting Bracket L/R Part A	2	0.156	0.312	Lasercut	91	33
27.1	MS	2x63x354	Picking Cam Bracket L/R Part B	2	0.35	0.7	Lasercut	92	33
28	MS	2x100x100	Picking Cam Bearing Bracket L/R	2	0.069	0.138	Lasercut	93	
29	MS	2x71x1949	Picking Arm Part A	1	1.89	1.89	Lasercut	94	34
29.1	MS	D24x72	Picking Arm Pin Part B	1	0.162	0.162	Round	131	34
30	MS	2x121x1600	Sley Cap Part A	1	2.973	2.973	Lasercut	95	35
30.1	MS	D20x60	Sley Cap Pin Part B_Handle Bracket	1	0.095	0.095	Round	131	35
31	MS	2x256x2874	Sley Race Housing	1	7.85	7.85	Lasercut	96/97	
32	MS	2x30x143	Spindle Bracket Inner Left/Right Part A	2	0.053	0.106	Lasercut	98	36
32.1	MS	2x20x36	Spindle Bracket Inner Left/Right Part B	2	0.01	0.02	Lasercut	98	36
33	MS	D280x8	Fly Wheel Part A Left/Right	2	3.629	7.258	Lasercut	99	37
33.1	MS	D60x30	Fly Wheel Part B Left/Right	2	0.492	0.984	Round	138	37
34	MS	2x42x1394	Treadle Left	1	0.916	0.916	Lasercut	100	
35	MS	2x42x1394	Treadle Right	1	0.916	0.916	Lasercut	101	
36	MS	2x73x159	Oscillating Back Rest Left Part A	1	0.134	0.134	Lasercut	102	38
36.1	MS	2x73x159	Oscillating Back Rest Left Part B	1	0.134	0.134	Lasercut	103	38
36.2	MS	2x32x1600	Oscillating Back Rest Left Part C	2	0.801	1.602	Lasercut	104	38
36.3	MS	D20x65	Oscillating Back Rest Left Part D	2	0.066	0.132	Round	139	38
37	MS	2x197x1610	Warp Beam Centre Part	1	4.983	4.983	Lasercut	105	39

37.1	MS	D25x70	Warp Beam Part B	2	0.253	0.506	Round	140	39
37.2	MS	D60x20	Not Required	2	0.329	0.658	Round	140	39
38	MS	D280x2	Warp Beam Flange Left/Right	2	0.926	1.852	Lasercut	106	
39	MS	D170x2	Let off Roller Part A L/R	2	0.306	0.612	Lasercut	107	40
39.1	MS	D170x2	Let off Roller Part B L/R	2	0.289	0.578	Lasercut	108	40
39.2	MS	2x55x402	Let off Roller Part C L/R	2	0.348	0.696	Lasercut	109	40
40	MS	2x32x115	Picking Spindle Stopper L/R	2	0.056	0.112	Lasercut	110	
41	FRP	33x150x375	Picking Cam Right	1	0.477	0.477		147	
42	FRP	33x150x375	Picking Cam Left	1	0.477	0.477		148	
43	MS	**5x37x317**	Take up Ratchet holder Bracket	1	0.274	0.274	Lasercut	111	
44	MS	**5x32x120**	Take up Guard Adjuster Part A	1	0.14	0.14	Lasercut	111	41
44.1	MS	D32x30	Take up Guard Adjuster Part B	1	0.125	0.125	Round	137	41
45	MS	**5x20x142**	Take up Guard Adjuster Horizontal Member	1	0.107	0.107	Lasercut	112	
46	MS	**5x97x221**	Take up guard Part A	1	0.32	0.32	Lasercut	112	42
46.1	MS	5x23x168	Take up guard Part B	1	0.151	0.151	Lasercut	113	42
46.2	MS	D32x30	Take up guard Part C	1	0.142	0.142	Round	137	42
46.3	MS	D10x35	Take up guard Part D	1	0.028	0.028	Round	137	42
47	MS	2x18x77	Take up Ratchet Part A	1	0.022	0.022	Lasercut	114	43
47.1	MS	D20x20	Take up Ratchet Part B	1	0.035	0.035	Round	138	43
48	MS	2x18x85	Take up Catch Part A	1	0.024	0.024	Lasercut	114	44
48.1	MS	D20x20	Take up Catch Part B	1	0.031	0.031	Round	138	44
49	MS	D178x35	Emery Roller Wheel	2	1.634	3.268	Casted	149	
50	MS	D60x22	Intermediate Compound Wheel	2	0.375	0.75	Casted	150	
51	MS	D156x18	Ratchet Compound Wheel	1	2.616	2.616	Casted	151	
52	MS	D20x56	Crank Pin Fly wheel side	2	0.08	0.16	Round	139	
53	MS	D30x201	Emery Roller Pin for Ratchet Wheel	1	0.488	0.488	Round	135	45
53.1	MS	D43x10	Emery Roller	2	0.067	0.134	Round	141	45

			End Bracket for Pin Ratchet Wheel (Right/Left)						
54	MS	D30x80	Emery Roller Pin Ratchet Wheel (Left Side)	1	0.252	0.252	Round	134	
55	MS	D43x10	Cloth / Front Roller End Bracket for Pin	4	0.088	0.352	Round	141	46
55.1	MS	D20x35	Cloth / Front Roller Pin	4	0.039	0.156	Round	141	46
56	MS	D20x50	Crank Arm Pin Sley Side	2	0.059	0.118	Round	141	
57	MS	D16x35	Picking Cam Bracket Pin L/R Part B	2	0.038	0.076	Round	131	
58	MS	D20x50	Picking Handle Part A	1	0.063	0.063	Round	136	47
58.1	MS	D20x105	Picking Handle Part B	1	0.247	0.247	Round	136	47
59	MS	D20x60	Pin for Take up lever for Ratchet	1	0.098	0.098	Round	137	
60	MS	25x40x75	Bracket Joining Front Rest and Picking Arm	1	0.262	0.262	Round	142	
61	MS	D10x255	Treadle Shaft	1	0.157	0.157	Round	142	
62	MS	D10x528	Picker Spindle	2	0.326	0.652	Round	142	
63	MS	D25x2000	Main Shaft	1	7.717	7.717	Round	142	
64	MS	D10x750	Heald Pulley shaft	1	0.463	0.463	Round	143	
65	Plastic	D50x16	Heald Reversing Pulley	2	0.193	0.386	Pulley	98	
66	MS	2x18x217	Sley Handle Bracket	1	0.052	0.052	Lasercut	115	
67	Wood	10x20x85	Sley Handle Part A	1	0.006	0.006		152	
68	Wood	10x20x85	Sley Handle Part B	1	0.006	0.006		152	
69	MS	OD43/ID37x1570	Cloth Roller	1	4.652	4.652	Round	145	
70	MS	OD43/ID37x1570	Front Roller	1	4.652	4.652	Round	145	
71	MS	OD43/ID37x1600	Emery Roller	1	4.741	4.741	Round	146	
72	Wood	35x70x2600	Sley Race	1	2.252	2.252		153	
73	Wood	45x48x1600	Reed Cap	1	1.342	1.342		154	
74	Wood	20x40x114	Spindle Holder Outer L/R	2	0.078	0.156	Lasercut	155	
75	MS	2x50x99	Seat Adjustment bracket Lower	4	0.078	0.312	Lasercut	123	48
76	MS	5x25x507	Seat Front Support	1	0.572	0.572	Lasercut	124	48
77	MS	2x81x488	Seat Post L/R	2	0.619	1.238	Lasercut	125	48
78	MS	D10x386	Cloth fixing rod	2	0.239	0.478	Lasercut	126	48

79	MS	2x91x1467	Loom Seat Lower	1	1.978	1.978	Lasercut	127	48
80	MS	2x66x1386	Loom Seat upper	1	1.355	1.355	Lasercut	128	
81	MS	5x20x145	Seat Adjustment bracket Upper Part A	2	0.078	0.156	Lasercut	129	
82	MS	5x20x145	Seat Adjustment bracket Upper Part B	2	0.078	0.156	Lasercut	129	
83	MS	5x20x145	Seat Adjustment bracket Upper Part B	2	0.078	0.156	Lasercut	130	
84	MS	2x298x307	Warp Beam Bracket Part A Left	1	1.049	1.049	Lasercut	116	18
85	MS	2x298x307	Warp Beam Bracket Part A Right (Mirror of Item No 84)	1	1.049	1.049	Lasercut	117	19
86	MS	2x38x115	Warp Beam Bracket Part B Left	1	0.043	0.043	Lasercut	118	18
87	MS	2x38x115	Warp Beam Bracket Part B Right (Mirror of Item No 84)	1	0.043	0.043	Lasercut	119	19
88	MS	2x222x293	Emery Roller Bracket Outer Left (Mirror of Item No 19)	1	0.734	0.734	Lasercut	120	25
89	MS	5x60x68	Warp Beam End Part for Pin	2	0.107	0.214	Lasercut	121	
90	MS	3x76x169	Insert Cross Frame Pulley Support Bracket	2	0.219	0.438	Lasercut	122	48_1
91	MS	2 x 73 x 525	Front Post L/R	2	0.596	1.192	Lasercut	121	
92	MS	D 30 x 12.5	Sleeve for Take up Ratchet holder Bracket	1	0.032	0.032	Round	146	

Fasteners for semi-automatic handloom							
Item No	**Material**	**Overall Size**	**Qty**				
101	Allen bolt	M6x10	14				
102	Allen bolt	M6x15	16				
103	Allen bolt	M6x20	6				
104	Allen bolt	M6x60	1				
105	Allen bolt	M8x15	60				
106	Allen bolt	M8x20	24				
107	Allen bolt	M8x30	12				
108	Allen bolt	M8x35	30				

109	Allen bolt	M8x40	40			
110	Allen bolt	M8x60	12			
111	Allen bolt	M8x65/70	8			
112	Allen bolt	M8x100	4			
113	Allen bolt	M10x15	2			
114	Cotter pin	Cotter Pin	10			
115	Circlip	Dia 8	4			
116	Circlip	Dia 10	4			
117	Nut	M6	50			
118	Nut	M8	150			
119	Nut	M10	2			
120	Plain washer	M6	50			
121	Plain washer	M8	150			
122	Plain washer	M10	2			
123	Spring washer	M6	50			
124	Spring washer	M8	150			
125	Spring washer	M10	2			
Bought out items for semi-automatic handloom						
130	Picker	87/(97) length	2			
131	Spring for cloth beam	OD20 - 160 working length	2			
132	Spring for backrest	OD10 - 70 working length	2			
133	Spring for warp beam	OD25 - 200 working length	2			
134	Spring for take up	OD10 - 30 working length	2			
135	nylon belt	2x30x400	2			
136	bearing (ID10)	6201-2RS1 (SKF)	8			
137	plumber block	P205	2			
138	emery strip		1			
139	nylon pulley		4			
140	foot pedal	Cycle	2			
141	tie up yarn	400mm	1			
142	Shuttle		1			

Appendix 2

BOM of Creel / stand

Item No	Material	Overall size	Qty	Wt./piece (Kg)	Total Wt.	Remarks	Detail Page No	SA Page No
1	MS	2x101x1812	5	2.823	14.115		3	2
2	MS	2x70x1075	2	1.185	2.37		4	2
3	MS	2x81x1078	2	1.357	2.714		5	2
4	MS	2x56x1176	1	1.022	1.022		6	2
5	MS	D16x25	2	0.024	0.048		7	2
				Total	**20.269**			
6	Wire	D4x21500	100					

Appendix 3

BOM of Warping drum

Item No	Material	Overall size	Qty	Wt./piece (Kg)	Total Wt.	Remarks
1	MS	2x91x1868	2	2.526	5.052	Lasercut
2	MS	2x87x740	2	0.937	1.874	Lasercut
3	MS	2x91x1363	2	1.909	3.818	Lasercut
4	MS	2x88x1938	2	2.712	5.424	Lasercut
5	MS	2x81x361	12	0.46	5.52	Lasercut
6	MS	2x50x167	4	0.129	0.516	Lasercut
7	MS	2x119x1341	6	2.52	15.12	Lasercut
8	MS	2x50x218	2	0.172	0.344	Lasercut
9	MS	**3x87x133**	2	0.256	0.512	Lasercut
10	MS	2x71x484	1	0.485	0.485	Lasercut
11	MS	2x72x300	2	0.336	0.672	Lasercut
12	MS	2x71x125	2	0.141	0.282	Lasercut
13	MS	2x71x125	2	0.136	0.272	Lasercut
14	MS	**3x57x124**	1	0.108	0.108	Lasercut
15	MS	**3x57x124**	1	0.108	0.108	Lasercut
16	MS	2x72x160	1	0.183	0.183	Lasercut
17	MS	2x68x100	2	0.104	0.208	Lasercut
18	MS	**3x280x280**	2	1.371	2.742	Lasercut
19	MS	2x197x1600	1	4.983	4.983	Lasercut
20	MS	2x119x1341	1	2.486	2.486	Lasercut
21	MS	D12x35	4	0.023	0.092	Round
22	MS	D43x5	4	0.54	2.16	Lasercut
23	MS	D25x150	1	0.561	0.561	Round
24	MS	D23x5	4	0.013	0.052	Lasercut
25	MS	D43x80	2	0.237	0.474	Section
26	MS	SQ25x1682	1	3.184	3.184	Section
27	MS	2mm / Existing parts 1	1	2.344	2.344	Lasercut
28	MS	2mm / Existing parts 1.1	4	0.191	0.764	Lasercut
29	MS	2mm / Existing parts 37	1	5.065	5.065	Lasercut
30	MS	Existing RD parts 37.1	1	0.253	0.253	Round
31	MS	**5mm/ Existing HEX parts 37.2**	2	0.109	0.218	Lasercut
32	MS	2mm / Existing parts 39/39.1/39.2	2	0.943	1.886	Lasercut
33	MS	2mm / Existing parts 39.1				Lasercut
34	MS	2mm / Existing parts39.2				Lasercut
35	MS	2mm / Existing parts 84/85	2	1.289	2.578	Lasercut
36	MS	2mm / Existing parts 86/87	2	0.108	0.216	Lasercut
				Total	**70.556**	
Fasteners of Warping drum						

Item No	Description	Size	Qty			
41	Allen bolt	M8x20	22			
92	Allen bolt	M8x25	4			
93	Allen bolt	M8x40	28			
94	Allen bolt	M8x80	8			

Bought out parts of Warping drum

Item No	Description	Overall size	Qty
123	Spring for warp beam	OD25 - 200 working length	4
127	plumber block	P205	2
128	Reed		1
129	Heald (nylon thin thread type)		2
130	Reed smaller		1
131	Heald smaller (nylon thin thread type)		1

Appendix 4

BOM of Winding wheel

Item No	Material	Overall size	Qty	Wt./piece (Kg)	Total Wt.	Remarks	Detail Page No	SA Page No
1	MS	2x81x257	1	0.309	0.309		3	2
2	MS	2x81x731	1	0.914	0.914		4	2
3	MS	2x81x431	1	0.528	0.528		5	2
4	MS	2x81x407	1	0.506	0.506		6	2

LIST OF ACRONYMS AND ABBREVIATIONS

ARTFED – Assam Apex Weavers and Artisans Co-operative Federation Ltd.

ASEAN – Association of South East Asian Nations

ASF - Acrylic staple fibre

ATIRA - Ahmedabad Textiles Research Association

B.C. – Before Christ

BOM – Bill of Material

BSM – Buyer Seller Meet

BTRA - Bombay Textile Research Association

CAM – Computer Aided Manufacturing

CATIA – Computer Aided Three-Dimensional Interactive Application

CHCDS - Comprehensive Handloom Cluster Development Scheme

CITI – Confederation of Indian Textile Industry

CNC – Computer Numerical Control

Co. – Company

CSTRI – Central Silk Technological Research Institute

DFA – Design for Assembly

DFM – Design for Manufacturing

Dept. – Department

DoD – Department of Design

EAC – Extra Assistant Commissioner

ET – Economic Times

EU – European Union

FDI – Foreign Direct Investment

FOM – Figures of Merit

FY – Financial Year

GDP – Gross Domestic Product

GD&T – Geometrical dimensioning and tolerancing

GI – Geographical Indication

GIA - Global Industry Analysts

GOI – Government of India

HEPC - Handloom Export Promotion Council

HHEC - Handloom and Handicrafts Export Corporation of India Ltd

HLG KETs - High-level expert group – Knowledge enabling technology

HPC - Handloom Production Centre

HSS - Hatkargha Sambardhan Sahayata

HTC - Handloom Training Centre

HTI - Handloom Training Institute

IHT – Institute of Handloom Technology

IIE – Indian Institute of Entrepreneurship

IIHF - India International Hand-woven Fair

IIHT – Indian Institute of Handloom Technology

IIT – Indian Institute of Technology

IJIRA - Indian Jute Industries Research Association

INR – Indian Rupee

ITI – Integrated Technology Index

ISO – International Organization for Standardization

KETs - Knowledge enabling technology

Kg – Kilogram

KVIC - Khadi & Village industries commission

KVIB - Khadi & Village industries Board

LH – Left hand

MANTRA – Man-made Textile Research Association

MGBBY - Mahatma Gandhi Bunkar Bima Yojna

MGNREGS - Mahatma Gandhi National Rural Employment Guarantee Scheme

MIG – Metal Inert Gas

MMF – Man-made Fibre

MRL – Manufacturing Readiness Level

MTBF - Mean time between failure

NA – Not Applicable

NASA - National Aeronautics and Space Administration

NERTPS - North Eastern Region Textile Promotion Scheme

NHDC – National Handloom Development Corporation

NIFT – National Institute of Fashion Technology

NITRA - Northern India Textile Research Association

Nos. – Numbers

NTCP-F - Novelty, technology, complexity, pace, fabrication/manufacturing

OECD - Organization for economic co-operation and development

PDCA – Plan, do, check and act

PMJJBY - Pradhan Mantri Jeevan Jyoti Bima Yojna

PMSBY - Pradhan Mantri Suraksha Bima Yojna

PPAP – Production Part Approval Process

PPM – Picks per minute

PPSF - Polypropylene staple fibre

PRSEUS - Pultruded Rod Stitched Efficient Utilized Structure

PSF - Polyester staple fibre

RBI – Reserve Bank of India

R&D – Research & Development

RH – Right hand

RTOs - Research and Technology Organizations

RQ – Research Questions

SA – Sub-assembly

SASMIRA - Synthetic and Art Silk Mills Research Association

SHDC - State handloom development corporation

SHGs - Self-help groups

SIRD – State Institute for Rural Development

SITRA - South India Textile Research Association

SPVs - Special purpose vehicles

Sq. m. – Square meter

TIG – Tungsten Inert Gas

TMA - Technology maturation assessment

TNV - Technology need value

TRL – Technology Readiness Level

TRA – Technology Readiness Assessment

UAE – United Arab Emirates

UK – United Kingdom

UNDP – United Nation Development Program

USD – United States Dollar

USA – United States of America

VSF - Viscose staple fibre

WBS - work breakdown structure

WESU - Weavers Extension Service Unit

WMSD - Work-related musculoskeletal disorders

WRA - Wool Research Association

WSC – Weavers Service Centre

Wt. - Weight

WTO – World Trade Organization

LIST OF PUBLICATIONS

Papers published (conferences)

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3) Mahato, M. & Das A. K. (2021). Design of a low cost adjustable seating system for comfort of weaver in ‘De Sign loom: A semi-automatic handloom. *ICoRD 2021 – Design for Tomorrow.* (doi.org/10.1007/978-981-16-0041-8_14)
4) Mahato, M. & Das A. K. (2022). Advance methods of ornamentation in fabrics woven using Fly-shuttle semi-automatic handloom. *NERC 2022 – Sustainable Science and Technology.*

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1) An ergonomically designed semi-automatic handloom with enhanced weaving productivity produced through laser cut and CNC bending for easy manufacturing, assembly, and transportation (Patent application number – 202131015272)