

Design of Devices for Making Beads from the Stems of Holy Basil

Yashwant Prasad*, Subir Kumar Saha & M R Ravi

Department of Mechanical Engineering, Indian Institute of Technology Delhi, New Delhi 110 016, India

Received 23 September 2023; revised 01 January 2024; accepted 24 September 2024

This paper addresses the challenges faced by artisans in India who rely on traditional hand-operated lathes to craft beads from the stems of Holy Basil for making garlands, resulting in discomfort, physical strain, and fatigue. The research focuses on the design improvements of a wood-turning lathe specifically customized for this purpose. It details the design of two bead-making devices: one incorporating a timing belt and pulley system and another with an electronic drive mechanism. The design methodology employed the Systems Engineering Process along with Human-Centered Design approach. A participatory design process was followed, with the design team collaborating closely with bead-making artisans, local entrepreneurs, and manufacturing partners to develop the devices. The effectiveness and performance of the new devices were assessed by comparing them to traditional hand-operated lathes based on productivity, maintenance requirements, earnings, and affordability. Results indicated that artisan productivity and earnings doubled with the new devices. Affordability was demonstrated through the sale of over 90 units, with increased earnings justifying the investment. This integrated design approach facilitated the broader adoption of the new bead-making devices, thereby promoting livelihoods of artisans and the sustainability of the design intervention. Drawing on over three years of experience, this paper presents a framework for designing products for Base of the Pyramid sectors. The framework can be applied to develop similar cluster-specific technologies for resource-constrained communities in rural areas.

Keywords: Base of the pyramid, Human-centered design, Sustainability, Systems engineering, Technology development

Introduction

This article deals with technology intervention in cottage industries, where families or small groups of individuals, referred to as clusters, produce goods on a small scale. These industries are often unorganized, with people frequently lacking suitable facilities for producing and processing goods, thus relying on outdated and labour-intensive techniques. This situation not only diminishes productivity and profitability but also threatens the sustainability of traditional businesses.¹ The technology interventions discussed in this article are cluster-specific, meaning that the specifications of similar requirements vary from one cluster to another. For instance, there are clusters in the northern part of India where artisans make beads of garland from Holy Basil stems. Different varieties of garland beads, in terms of shape and size, are produced in different clusters, and the processes of their production also differ. Therefore, customization is required to fulfil the specific requirements of each cluster. Additionally, as the clusters belong to the Base of the Pyramid (BoP)

population^{2,3}, affordability is a major concern. To address these challenges, scaling down technologies is crucial^{4,5}, ensuring that the tools and equipment used are suitable for the size of cottage industry operations. Scaling down technologies offer flexibility, allowing cottage industries to adapt their production processes to changing demands or specific requirements. Moreover, it becomes easier to access them, even with limited financial resources. This approach empowers local communities and promotes sustainability.⁶

Communities at the grassroots⁷ have made several efforts to develop innovative solutions to address their problem based on their accumulated experiences over years. However, the transformation and realization of these solutions into finished products become challenging due to a lack of knowledge, expertise, and appropriate facilities required for development.^{8,9} Such grassroots technological innovations necessitate systematic engineering management for design optimization and standardization to suit specific requirements of communities. Design is a continuous process of refinement, where solutions evolve through iterative cycles from initial concept to a refined product.¹⁰ The Systems Engineering Process (SEP)¹¹

*Author for Correspondence
E-mail: prasadyash2011@gmail.com

is well-suited for managing iterative design journey of engineering problems. It offers a structured framework that starts with defining requirements and guides in progressively refining details through a top-down comprehensive, iterative, and recursive problem-solving approach applied sequentially through all stages of technology development. The output of SEP consists of documents defining system requirements and design solution which is crucial for information dissemination and technology transfer. This paper presents the development of devices for making beads from the stem of Holy Basil by adapting SEP. The developed devices are special purpose lathes customized to meet the specific requirements of bead making artisans in India.

Background and Research Motivation

In rural areas around Mathura, U.P., and Bharatpur, Rajasthan, India, more than 2000 artisans, both men and women, craft beads for garlands from the stems of Holy Basil plant.¹² The size of the beads typically ranges from 1 to 25 mm in diameter, as shown in Fig. 1. The garlands made from these beads hold significant spiritual importance and are considered sacred. Devotees utilize them in spiritual practices, such as chanting *mantras*, and often wear them as necklaces.¹³ Consequently, there exists a substantial demand for these garlands both within India and abroad. Artisans traditionally make these beads using a hand-operated wood-turning lathe developed locally

as shown in Fig. 2(a). Generally, they craft beads with their right hand using a cutting tool, while their left hand continuously cranks the spindle carrying the stem of the Holy Basil. However, this manual powering of the setup causes physical strain. Many artisans become tired within a few hours of operation, experiencing shoulder and back pain. With the traditional hand-operated lathe, women could only make smaller beads up to 10 mm in diameter. To address the issues associated with drudgery in bead making, the artisans' community in Bharatpur developed a mechanized device powered by a 40-watt DC motor, as depicted in Fig. 2(b). However, this initial device had several shortcomings. While operating it, artisans had to hold the motor with one hand and stop it manually with their fingers after making each bead. This often led to muscle pain and discomfort. Moreover, due to the cumbersome and inconvenient process, artisans struggled to produce beads of the desired quality. The Rural Technology Action Group (RuTAG) intervened further and redesigned the device, as shown in Fig. 2(c), to address these issues.¹⁴ A rail using two rods was designed to guide the translation of the DC motor, making the operation more convenient. Additionally, a housing was developed so that the motor could rest over the rail, relieving artisans from the need to hold it with their hands. Moreover, a limit switch was integrated to start and stop the motor, resolving the problem of muscle pain. These improvements resulted in a significant improvement in productivity and the quality of the produced beads. Some artisans reported that their earnings doubled. However, a post-dissemination survey revealed shortcomings and limitations of DC motor powered device.¹² The DC motor heated up within an hour of operation. Since one hand was required to hold and slide the motor, artisans had to wait for 30 to 40 minutes for the motor to cool down. Furthermore, the device generated vibration and noise, which not only irritated the artisans but also disturbed their neighbours. Most of the demand of these garlands was met by the cluster

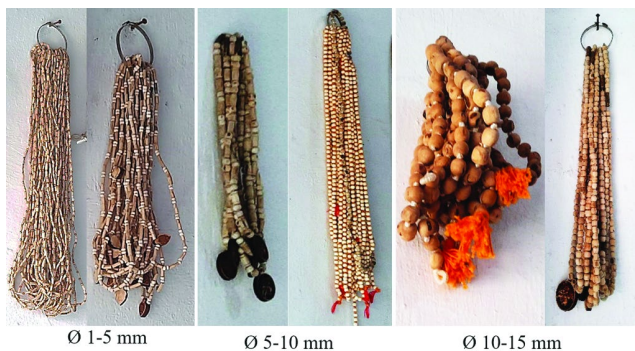


Fig. 1 — Garlands made from beads of Holy Basil

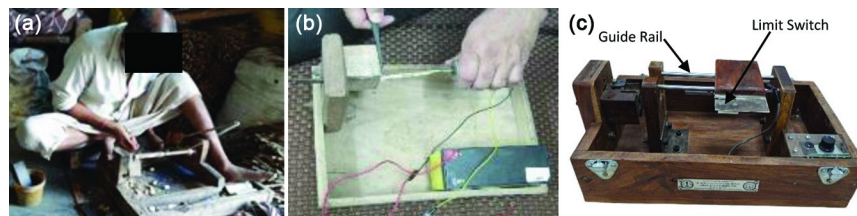


Fig. 2 — Existing devices for making beads: (a) Traditional hand-operated lathe, (b) Community innovated mechanised device, (c) DC motor powered device redesigned by RuTAG

in Jait village. However, this device was not suitable for the artisans in this cluster as they also produce beads of larger diameter (up to 25 mm), and the capability of the redesigned device was limited to 10 mm in diameter. The artisans at the time preferred the traditional hand-operated lathe because, despite the drudgery involved, they had grown accustomed to produce beads more quickly with this setup. However, they highlighted their pain points. Due to physical exhaustion, artisans were able to work only for 2 to 3 hours a day. To overcome these shortcomings and limitations, a new device powered by a 100-watt AC motor was developed, as shown in Fig. 3. Study by Prasad *et al.*¹² can be referred for detailed design information. In this design, the existing guide rail was replaced by a standard MGN 15 linear guide rail¹⁵ with bearing that had capability to absorb sound and vibration. However, artisans did not adopt this device either, primarily due to two key reasons: (1) the inconvenience caused by the high operating speed (8000 rpm) of the AC motor, and (2) the lack of durability and availability of the pin used in the new design. Additionally, cracks developed on the base plank over time. Efforts were also made to design a device that could be manufactured locally using local resources. But it was not feasible due to the required sophistication vis-a-vis the limitations of the local manufacturing facility at that time.

The existing technology required further upgrading to accommodate the diverse range of requirements, allowing artisans to use it according to their specific needs. From field trials, expert advice, and a literature review,¹⁶⁻¹⁸ it was realized that a more participative approach was needed in the design. Therefore, it was decided to involve artisans and manufacturers in the design process. Additionally, the design process did not explicitly and systematically incorporate the steps of creating alternative design concepts and system configurations followed by trade-off studies. These activities were planned and followed systematically in

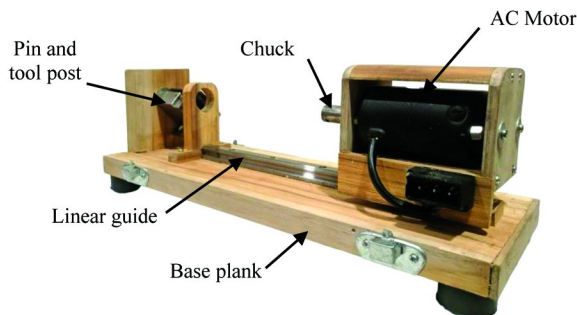


Fig. 3 — Device powered by 100-watt AC motor (Baseline)

the subsequent iterations of the design. The 100-watt AC motor-powered device shown in Fig. 3 served as the baseline for the next stage of development reported in this article. The next section discusses the methodology that details the adaptation of the Systems Engineering Process.

Methodology

The design intervention presented in this article focuses on livelihood-centric technology development for rural communities. Need identification, technology development, and dissemination are the three major stages in rural technology interventions. Human-Centered Design,¹⁹ System Thinking Approach¹⁸ and Design for Sustainability²⁰ were the methodologies employed during the intervention, as suggested in the literature. This paper primarily focuses on the technology development stage by adapting the Systems Engineering Process,¹¹ as shown in Fig. 4. Data gathered from the need identification stage were documented as concept notes, which contained information about the intervention context, including the problem background, the existing state of technology, beneficiaries, their needs, problem statement, objectives, environment, and constraints. The concept notes served as input to the SEP. The need identification and solution generation processes were iterative and refined based on feedback and need assessments. The outputs of the SEP included system architecture, specifications, and baselines, which were then used in subsequent stages of technology development, encompassing preliminary and detailed design.

Following the SEP, requirements were converted into specifications, which led to the creation of design documentation. Functional, performance, and design constraint requirements were defined through requirements analysis. Higher-level functions identified during this analysis were decomposed into lower-level secondary functions, with their performance requirements established through functional analysis. For instance, the primary requirement was to develop a mechanized device to reduce the drudgery involved in the bead-making process. Facilitating bead making was the primary function of this device, while supplying power and the required torque were derived as secondary functions necessary to fulfil the primary requirement. Solutions to meet these requirements were generated through design synthesis, where alternative system concepts, configurations, and elements were created, and a

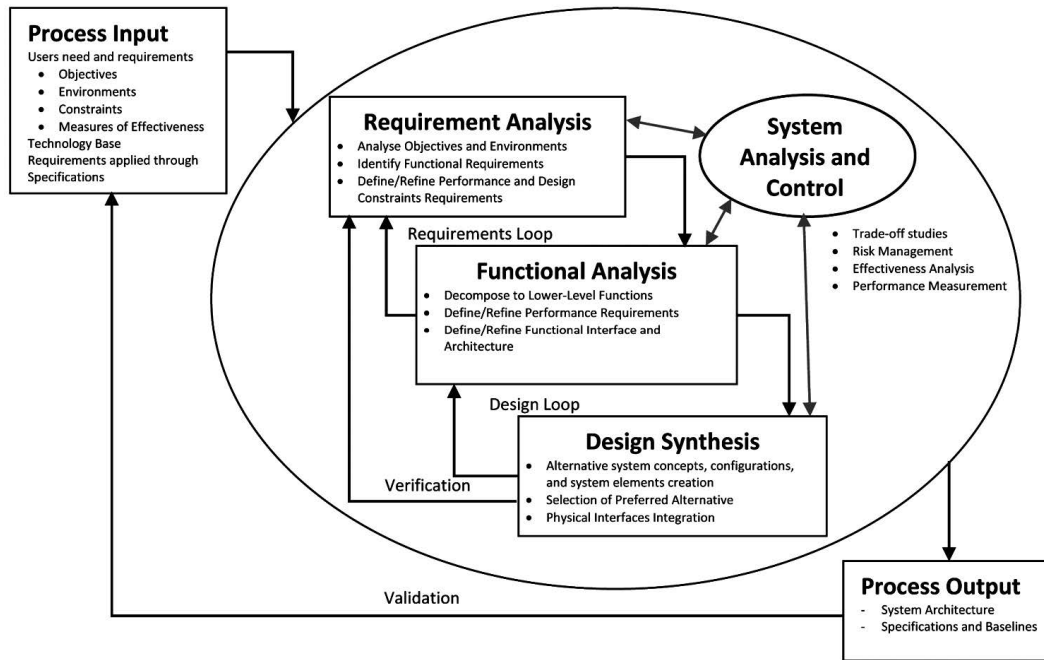


Fig. 4 — Systems engineering process¹¹

preferred alternative was selected. Creo Parametric software²¹ was utilized as a CAD tool to create 3D models and drawings. Requirements and solutions were verified and validated through feedback mechanisms. Trade-off studies, risk management, effectiveness analysis, and performance measurement were conducted at all stages of the SEP. Trade-off studies, using a decision matrix, helped select preferred solutions, while Failure Mode and Effect Analysis (FMEA)²² was conducted for risk mitigation. The system's effectiveness and technical performance were evaluated through visual inspection, demonstrations, field trials, and feedback from artisans. Prototypes were fabricated and tested both in the lab and field to validate the design solutions.

A participatory design approach^{23,24} was followed during the design process. The devices were developed at an academic institution, with faculty, research scholars, engineers, engineering students, NGO partners, artisans, and manufacturers as the design team. Approximately, ten artisans were consistently involved in the design process, sharing their traditional knowledge and experiences of bead making. The information shared by artisans served as design input. Over multiple design iterations spanning over three years, the bead-making devices evolved into an acceptable form. The design and development of these devices are explained in more detail in the following sections.

Table 1 — System requirements description

Task area	Description
1 Artisans' need	A mechanized wood-turning lathe to produce garland beads.
2 Constraint	The stem of the Holy Basil is bent and non-uniform throughout its length. Operable for 8 hours per day.
3 Operational requirement	Operable by both men and women.
4 Functional requirement	Simultaneous turning and drilling operation.
5 Performance requirement	Artisans should be able to make 5–25 mm diameter beads.
6 Interface requirement	Device should run on a 220V single phase AC supply.
7 Human system integration	Traditional cutting tool should be compatible. Artisans should be able to operate the device by sitting on the floor or chair as per their convenience.

System Requirements and Specifications

The system requirements outlined in Table 1 provide a comprehensive overview of the objectives and constraints surrounding the development of a motorized wood-turning lathe for producing garland beads. These articulated requirements address various critical aspects related to the functionality, performance, and operability of the lathe. Notably, the requirement for artisans to produce beads within a diameter range of 5 to 25 mm reflects the adaptability of lathe to diverse bead sizes, catering to varying

Table 2—Subsystem level functional requirements	
Requirement	Description
1 Motor torque and stem rotation	The system must include a motor capable of supplying the necessary torque to rotate stems up to 25 mm in diameter.
2 Cutting rotational speed	The system should be capable of setting and maintaining cutting rotational speeds between 1500 and 3000 rpm.
3 Linear guide for motor translation	The device must incorporate a linear guide mechanism to enable precise translation of the motor housing.
4 Hole creation	The system should feature a pin designed to create holes of 1 to 2 mm diameter in the bead.
5 Chuck for holding stem	The system must have a chuck capable of securely holding stems with diameters ranging from 5 to 25 mm.
6 Stem length adjustment	The device must allow for easy adjustment to accommodate different stem lengths up to 200 mm.
7 Bed to support device structure	The device must be equipped with a stable bed or base to support the overall structure and ensure stability during operation.

design preferences and market demands. The system must also accommodate the unique constraints posed by the non-uniform stems of Holy Basil, necessitating a design capable of effectively handling such variability while operating continuously for eight hours per day. Additionally, the device should be capable of turning workpieces while keeping the noise level within acceptable limits (less than 85 dBA).²⁵ Moreover, it should be operable by both men and women, contributing to its potential widespread adoption and impact within artisan communities.

On the other hand, Table 2 highlights into the specific subsystem-level functional and performance requirements that must be met to fulfil the overarching system requirements outlined in Table 1. Each functional requirement addresses a critical aspect of the operation of the device, such as motor torque for stem rotation, cutting speed, linear guide mechanism, hole creation capability, chuck design for stem holding, and stem length adjustment. These requirements highlight the complexities involved in designing a wood-turning lathe capable of accommodating the unique characteristics of stems and producing beads within the specified diameter range.

Design Solutions

The prototype shown in Fig. 3 represents the preliminary design, serving as the baseline model for the detailed design stage of development. The objectives in this stage were to design a system to achieve the desired cutting rotational speed, select a suitable linear guide, and redesign the components: the pin, tool post, and base plank. To meet the requirement for cutting rotational speed, two different design approaches were implemented. The first approach achieved the desired operational speed

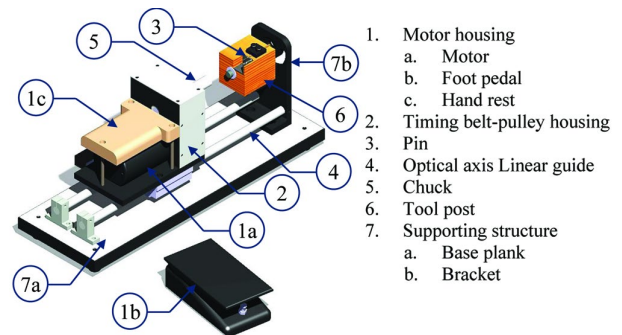


Fig. 5 — Device with 100-watt AC motor powered device with timing belt-pulley drive (MTBP)

through a mechanical drive consisting of a timing belt and pulley assembly, while the second approach utilized an electronic drive for speed control. Consequently, these approaches led to the development of two distinct models of the device. Based on derived functional requirements mentioned in Table 2, the system was decomposed into seven subsystems: the motor, power transmission unit, linear guide, pin, chuck, tool post, and supporting structure. The two models differ specifically in their motor and power transmission unit configurations. The detailed design and specifications of both models are explained in the subsections below.

Model with Timing Belt and Pulley (MTBP)

The baseline model (see Fig. 3) was detailed to meet the functional and performance requirements defined in Table 2. The primary design objective was to develop a rotational speed reduction unit to enable artisans to make beads conveniently. A device, powered by a 100-watt AC motor with a timing belt and pulley was designed and developed, as depicted in Fig. 5. The device occupied a space of $460 \times 190 \times 150$ mm and had a total weight of approximately 7 kg.

Table 3 — Decision matrix for the selection of power transmission unit

Sl. No.	Parameter	Weight	Belt drive	Chain drive	Gear drive
1	Cost	0.4	5	4	3
2	Ability to absorb sound and vibration	0.25	5	2	3
3	Reliability	0.2	2	3	5
4	Maintainability	0.15	5	3	3
	Total score	1	4.4	3.15	3.4

It was engineered to operate at 2000 rpm and cut beads between 5 to 25 mm in diameter. The design prioritized the use of standard components to ensure ease of manufacturing and maintenance. The design details of each subsystem are discussed in the subsections below.

Selection of Motor

Hand cranking by human can generate approximately 54 watts of power,²⁶ which was found sufficient for crafting beads with a diameter of 25 mm, as observed from field studies. Market surveys indicated that AC motors were cheaper, readily available, and easier to maintain and repair compared to DC motors. During field research, some artisans suggested to use a pedal-operated sewing machine motor to power the device. Given that the selection and design of the device components depended on the choice of motor, it was decided to use the same 100-watt AC motor for sewing machine used in the baseline model. It is manufactured by USHA company. This motor was chosen because it is readily available in the market and comes with a one-year warranty. It also met the power requirements. Since the motor's operating speed was around 8000 rpm, a power transmission unit was necessary to reduce the rotational speed to the desired range of 1500 to 3000 rpm.

Design of Power Transmission Unit

Based on the experience from field studies the design team decided to set the rotational cutting speed to around 2000 rpm using mechanical systems. Mechanically, speed is reduced using chain drive, gear drive, and belt drive. These drives were evaluated by conducting decision matrix analyses²⁷ with respect to cost, reliability, ability to absorb vibration and noise, and maintainability. Weights were provided to the parameters based on their relative importance such that their sum is unity. A Five-point scale was used to rate alternatives, with 5 being the least cost, best absorber of sound and vibration, most reliable, and easily maintainable. A belt drive was selected based on the decision matrix shown in Table 3. It was decided to select a timing belt compared to a flat or V

Table 4 — Design conditions for selection of timing belt and pulley

Parameter	Design Condition
1 Machine type	Wood working lathe
2 Power transmission	100-watt, 8000 rpm AC motor
3 Operation duration per day	8 to 12 hours as regular use
4 Speed ratio	4
5 Initial centre distance	50 mm
6 Smaller pulley bore diameter	6.3 mm

Table 5 — Specification of the timing belt and pulley

S. No	Component	Specification	Standard
1	Small pulley	14 teeth	14-3m-09 HTD
2	Large pulley	56 teeth	56-3m-09 HTD
3	Belt length	207 mm	HTD 207 – 3m

Note: 3M Metric High Torque Drive (HTD) pulleys and belt with 3 mm pitch were selected

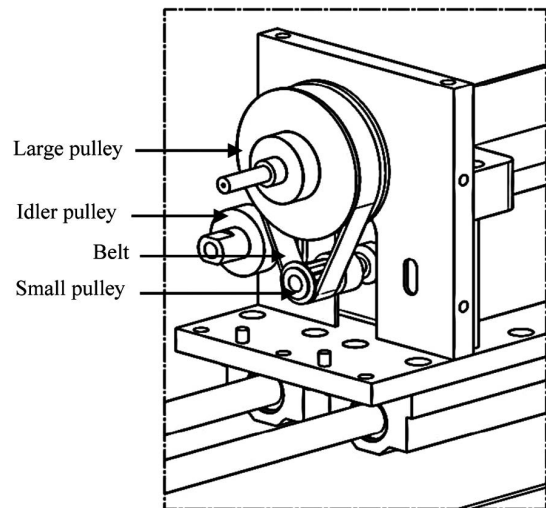


Fig. 6 — Assembly of timing belt and pulley

belt, as it does not slip and consistently transmits power at constant angular speed. The steps involved in selection of timing belt and pulley were defining design conditions, calculating design power, selecting belt type and pulley, belt length and width, and adjusting the center distance.²⁸ The design conditions considered are outlined in Table 4. Specifications of the chosen timing belt and pulley are provided in Table 5, while Fig. 6 illustrates the assembly.

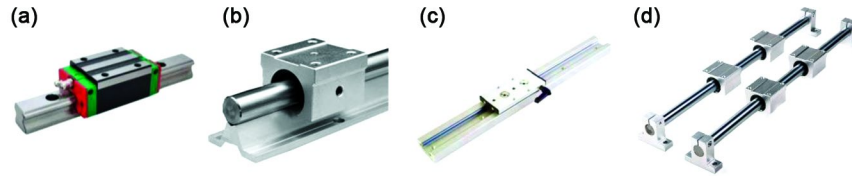


Fig. 7 — Types of linear guides: (a) MGN linear guide (Make: HIWIN), (b) SBR linear guide (Make: ZYSL), (c) SGR linear guide (ARESWIN), and (d) Optical axis linear guide (Precision bearing house)

Selection of Linear Guide

The length of the workpiece decreases after the production of every bead, necessitating a reduction in the distance between the chuck and the tool post for crafting the next bead. Preferred practices of artisans suggested that sliding the motor housing towards the tool post was more convenient for adjusting this distance. Moreover, the workpieces were often bent with non-uniform cross-sections along their length, resulting in fluctuating loads due to the eccentric mass of the rotating workpiece. Consequently, the system experienced vibrations. To address this issue, a decision was made to select a cost-effective linear guide capable of absorbing vibrations. Among the four different types of linear guide rail and bearing designs available in the market, as illustrated in Fig. 7, the optical axis linear guide (Fig. 7(d)) was chosen as the most cost-effective solution for meeting the requirements.

It was decided to keep the length of the rail as 400 mm so that it could accommodate a 200 mm long workpiece, the motor and the timing belt-pulley housing. The Goodman equation of distortion energy theory was used to calculate the diameter of the rail.²⁹ It was assumed that a fluctuating bending point load (F) acts at the center of a simply supported beam due to unbalance, as shown in Fig. 8. The magnitude of force due to the eccentric mass of the rotating workpiece was calculated using the equation, $F = m_e e \omega^2$ ⁽³⁰⁾ where the eccentric mass (m_e) was taken as 20 grams, eccentricity (e) was assumed to be the maximum radius of the workpiece which was 12.5 mm, and the angular speed was taken as the cutting speed of 3000 rpm, i.e. 314 rad/sec. The magnitude of the fluctuating load was calculated to be approximately 25 N. Consequently, the diameter of the rail was calculated to be 11 mm. The nearest standard available size was MCS12,⁽³¹⁾ which had a diameter of 12 mm. This rail is case-hardened and ground chrome plated. To ensure better stability of the motor housing, the long length linear bearing SC12LUU was selected.

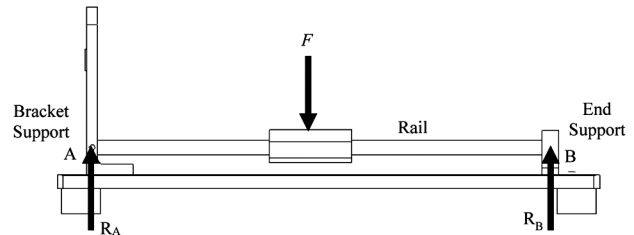


Fig. 8 — Loading condition

Design of Pin and Tool Post

The most critical failure mode assessed by performing FMEA was the pin breaking in the baseline model. The dowel pin broke frequently and was not available locally, prompting the need for an alternative solution. To address this issue, the design team organized several brainstorming sessions with artisans and decided to collaborate with a local blacksmith to develop a solution for making holes in the bead. The identified blacksmith had experience in making pins and the tool post of the traditional hand-operated device as shown in Fig. 2(a). The pins were made by forging used components gathered from the trash. The artisans informed that these pins were more durable, and sometimes they last for three months. As the pin was locally manufactured, it was affordable and easily replaceable. This was one of the positive aspects of participatory development approach applied during the design synthesis of SEP. It was decided to use this pin with modifications in design to accommodate it. A clamp was designed to fix the pin on the traditional tool post, as shown in Fig. 9(a). Artisans preferred different orientations of the tool post as per their convenience. So, a 90° arc was cut (Fig. 9b) on the bracket to allow for adjustment of the tool post orientation as per their preference.

Design of Supporting Structure

The supporting structure includes the base plank and bracket. The primary objective in designing the base plank was to select an appropriate material. Suitable options available in the market included solid wood, plywood, Bakelite, and hardboard. Based on experience, the manufacturer recommended a 12 mm

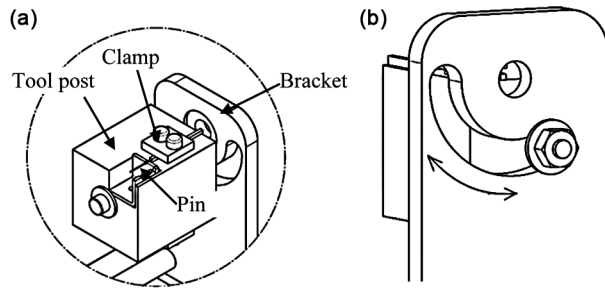


Fig. 9 — Configuration of traditional pin, tool post and bracket in the new design: (a) Assembly of traditional tool post and pin, and (b) Provision to orient the tool post

thick Bakelite sheet due to its water resistance, ability to absorb vibrations, and resistance to cracking. The function of the bracket was to support the tool post and the linear guide rail. The design incorporated threaded holes and fasteners to secure and assemble the design elements. Consequently, plain carbon steel, also known as mild steel, was selected to fabricate the bracket.

Model with Electronic Drive (MED)

The manufacturing time of the MTBP was around 30 days for 10 sets of devices, primarily due to the customization required for the timing belt pulley drive. Additionally, components such as the carbon brush of the motor, foot pedal, and the timing belt of this model required frequent replacement. Moreover, many artisans expressed a desire to operate at speeds higher than 2000 rpm. The development of the Model with Electronic Drive aimed to provide variable speed operation, preferred by artisans with reduced number of components to minimize manufacturing time and maintenance requirements. To meet these objectives, the existing motor and timing belt pulley drive were replaced with a 550-watt servo motor. Even though bead crafting requires only 100 watts, 550-watt motor was chosen for its capability of integrated speed variation using an electronic drive. This motor allowed variation in speed up to 4500 rpm. This change not only provided the needed speed flexibility but also simplified the device's design by eliminating the timing belt and pulley system. Six components were removed, namely the bracket, two pulleys, a cover, and two shafts. This reduction halved the fabrication time and thus significantly decreased maintenance requirements. Additionally, feedback from artisans indicated a preference for operating the device while seated on the floor, leading to the replacement of the foot pedal with a hand-operated limit switch for easier use in this posture. Other

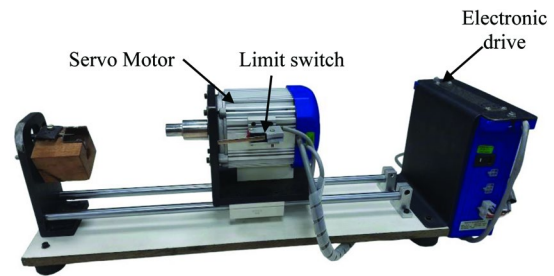


Fig. 10 — 550-watt servo motor powered device (MED)

design elements were accordingly modified to integrate the servo motor and hand-operated limit switch. The design modifications resulted in a device measuring 600×180×150 mm and weighing 8.5 kg, which was 1.5 kg heavier than the previous model due to the heavier motor. Overall, MED successfully met its development objectives by incorporating a servo motor, which simplified the design and made manufacturing easier. It is shown in Fig. 10.

Both MTBP and MED were validated in bead-making clusters to ensure they met the requirements of artisans. The upgraded devices are shown in Fig. 11 and improvements are highlighted in Table 6. The design validation and impact are explained in the next section.

Design Validation and Impact

The effectiveness of MTBP and MED was validated iteratively over more than two years in two bead-making clusters through field tests and evaluations. Prototypes of MTBP underwent multiple cycles of iteration with validation in both the lab and field. Once the final version of this model was ready, over 30 artisans were trained to operate the device. Subsequently, 10 devices of this were distributed among the artisans for long-term testing of performance and utility. Four artisans received the device for free, as remuneration for their substantial contributions of time and experience in design related activities. Additionally, six artisans purchased the device at a discounted price (~50%) from the facility available at the academic institute. The operation of these devices was observed for one year, during which they were used for 4 to 8 hours daily. Similarly, the prototype of MED was tested in bead-making clusters for three months to assess the requirement for variable rotational cutting speeds. After testing and evaluation, both devices were demonstrated to more than 50 artisans, followed by a study on their adoption within the artisans' community. Data collected from post-dissemination

Table 6 — Summary of improvement of the devices

Model	Details	Improvements
1. Baseline model	Size: 400 × 100 × 100 mm Weight: 5 kg Cost: ₹ 8000	<ol style="list-style-type: none"> Artisans were able to make beads up to 20 mm in diameter. Noise (65–85 dBA) levels were within comfortable limits. Selection of standard motor. Eased translation of the motor housing due to the addition of a linear guide.
2. Model with timing belt-pulley (MTBP)	Size: 460 × 190 × 100 mm Weight: 7 kg Cost: ₹ 15000	<ol style="list-style-type: none"> Both men and women were able make beads up to 25 mm in diameter comfortably. The operating speed was reduced from 8000 rpm to 2000 rpm. Artisans were able to work for longer durations (4–8 hours). Life of pin increased from 1–5 days to up to 3 months. Brackets were replaced from wood to mild steel. Base plank material was replaced from wood to Bakelite that resisted cracking.
3. Model with electronic drive (MED)	Size: 600 × 80 × 150 mm Weight: 8.5 kg Cost: ₹ 18000	<ol style="list-style-type: none"> Operating speeds of 2000–3000 rpm was provided. Noise levels were between 65–75 dBA. No. of customized components (6) were reduced. This reduced fabrication time and maintenance requirements. Local maintenance and repair facility was established.



Fig. 11 — Bead-making devices with upgrades shown in sequence: (a) Baseline model, (b) MTBP and (c) MED

surveys and field research was used to analyze productivity, maintenance requirements, earning and affordability. These parameters are discussed in the following subsections.

Productivity

According to the survey conducted with artisans, approximately 80% of the total bead production consisted of beads less than 10 mm in diameter, while 20% were between 10 to 25 mm. Production of beads larger than 15 mm was infrequent and typically based on specific demand. Therefore, the productivity of artisans producing beads in the 5 to 10 mm and 10 to 15 mm ranges was closely observed and analysed. The results, illustrated in bar diagrams in Fig. 12, indicate that artisans using both models were able to produce beads ranging from 5 to 15 mm in diameter relatively faster. Productivity nearly doubled with MTBP and more than doubled with MED compared to traditional devices (Fig. 12). This significant increase in

productivity demonstrates the effectiveness of both models in enhancing the bead-making process.

The motor-powered devices significantly enhanced the convenience of bead making for the artisans. By reducing the operating speed from 8000 rpm in the baseline model to 2000 rpm in the MTBP and 2000–3000 rpm in the MED has improved safety during operation. The improved ergonomics allowed artisans to work in more comfortable body postures, reducing physical strain. As a result, artisans reported being able to work for longer durations, increasing from the typical 2–3 hours with traditional devices to 4–8 hours with both the new models. The mechanization of these devices also enabled women to produce beads larger than 10 mm diameter conveniently, a task that was rare and challenging with traditional hand-operated device. This shift not only increased productivity but also expanded the range of products that artisans could offer, demonstrating improvements in both capability and comfort.

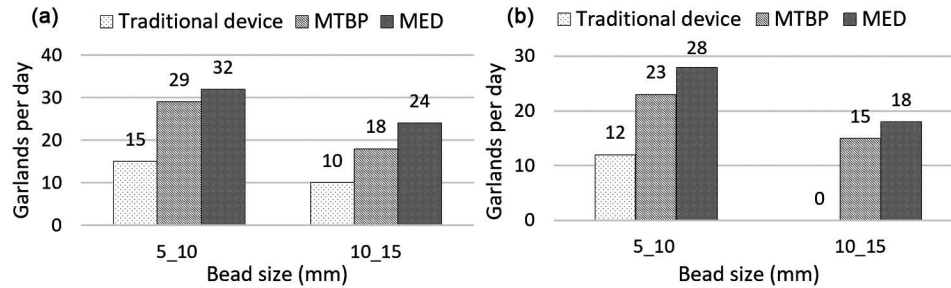


Fig. 12 — Productivity comparison of devices: (a) Male artisans, (b) Female artisans

Maintenance Requirements

Although MTBP was effective, it required frequent maintenance and servicing. The carbon brushes needed replacement as often as every month, timing belt every six month, and the foot pedal typically required annual replacement. These spare parts were readily available and affordable, making maintenance manageable for the artisans. To streamline maintenance and improve reliability, MED was developed with a focus on reducing the number of components and incorporating more durable parts. As a result, it exhibited fewer maintenance issues. In the MED, only the fuse in the motor drive and the limit switch required replacement, which was provided by a local entrepreneur. This demonstrated the improved ease of maintenance.

Earning

Traditionally, more male artisans were engaged in bead making with an expected monthly income of ₹7000 to ₹10,000 if they worked 8 hours a day for 20 days a month. However, due to the physical strain and fatigue associated with traditional devices, most artisans managed to work only for 2 to 3 hours a day, resulting in significantly lower earnings. With the introduction of the new models, an analysis of productivity, raw material costs, and the selling price of garlands indicated that artisans could potentially earn up to ₹15,000 to ₹25,000 per month. This increase was confirmed by several artisans who reported higher earnings. Female artisans, in particular, experienced a substantial boost in income due to the significant increase in productivity and the ability to produce larger beads and work longer hours with the motorized devices. Additionally, some women who had not previously engaged in bead making began to do so with the new devices. These improvements in overall earnings demonstrated the potential of both models to contribute to better financial stability for the families of artisans.

Affordability

The cost of MTBP was ₹15,000 while MED was priced at ₹18,000. Note that, the traditional hand-operated device was available for ₹1,200. The new devices were expensive but were affordable by the artisans. To assess affordability, 10 devices of each model were distributed to the artisans to study rental and ownership business models. The payback period of the devices ranged from 1 to 3 months, making ownership a more favourable option for artisans. Consequently, around 70 devices of MTBP and 20 devices of MED were sold by the manufacturer within two years, with expectations of further sales in the future. This demonstrated that while the initial cost was high, the increased productivity and earnings due to the new models justified the investment.

Over two-years of iterative validation process in two bead-making clusters, both models proved effective in meeting technical and operational needs. Rigorous testing and refinement led to the development of reliable final versions. Both models significantly enhanced productivity, with MED showing the most substantial improvement. The motorized devices were more beneficial for female artisans who could now produce larger diameter beads. These devices improved convenience, enabling longer working hours and increased comfort, thereby reducing drudgery. MTBP, despite initial mechanical issues, provided a foundation for the more refined and reliable MED, which demonstrated higher satisfaction and increased economic benefits to the artisans. As a result, improved financial stability was achieved for the artisans, notably for the women. Despite initial concerns with the price, the affordability and rapid payback period justified their adoption, leading to substantial sales and community-wide adoption.

Conclusions

This paper proposed the implementation of the Systems Engineering Process and Human-Centered

Design in new product development for the Base of the Pyramid sector, addressing a gap in current practices. The framework effectively guided designers in bead-making interventions through a participatory development process that involved artisans and manufacturers, ensuring the design meeting the practical needs. This integrated approach resulted in significant improvements in productivity and comfort, validated by a doubling of artisans' earnings. However, the applicability of these devices for producing beads smaller than 5 mm in diameter was not assessed, and the design can only be operated by right-handed users. The study was concentrated in one geographical location. Future research could explore the adoption of these devices in other wooden bead-making communities across India. Additionally, the proposed framework can be adapted for developing cluster-specific rural technologies, such as energy-efficient kilns for firing earthenware, presenting significant opportunities for implementation across diverse pottery communities.

Acknowledgment

The authors wish to acknowledge the Office of the PSA, Government of India for their financial support to this project. The authors would like to thank RuTAG IIT Delhi team for supporting the project in design and development activities. The authors would like to thank the NGOs Lupin Human Welfare and Research Foundation, and Human Social Welfare Society for their support in field activities like workshops, field research, testing, demonstration, and training.

References

- Kandachar P & Halme M, *Farewell to Pyramids: How Can Business and Technology Help to Eradicate Poverty?* (Greenleaf) 2008.
- Prahalad C K, Bottom of the pyramid as a source of breakthrough innovations, *J Prod Innov Manag*, **29(1)** (2012) 6–12, doi: 10.1111/j.1540-5885.2011.00874.x.
- Simanis E & Hart S, Expanding possibilities at the base of the pyramid, *Innov Technol Gov Glob*, **1(1)** (2006) 43–51.
- Schumacher E F, *Small is beautiful: A study of economics as if people mattered* (Random House) 2011.
- Johansson A, Kisch P & Mirata M, Distributed economies: A new engine for innovation, *J Clean Prod*, **13(10–11)** (2005) 971–979, <https://doi.org/10.1016/j.jclepro.2004.12.015>.
- Tripathi R, Shastri R K & Agarwal S, Survival and growth strategies for small-and medium-scale enterprises in India: A key for sustainable development, *Driv Econ Innov Ent*, 2013, 163–174, doi: 10.1007/978-81-322-0746-7_14.
- Smith A, Fressoli M & Thomas H, Grassroots innovation movements: Challenges and contributions, *J Clean Prod*, **63** (2014) 114–124, <https://doi.org/10.1016/j.jclepro.2012.12.025>.
- Sianipar C P M, Yudoko G, Adhiutama A & Dowaki K, Community empowerment through appropriate technology: Sustaining the sustainable development, *Proc Env Sci*, **17** (2013) 1007–1016.
- Donaldson K, Product design in less industrialised economies: constraints and opportunities in Kenya, *Res Eng Design*, **17** (2006) 135–155, doi: 10.1007/s00163-006-0017-3.
- Suwa M, Gero J & Purcell T, Unexpected discoveries and S-invention of design requirements: Important vehicles for a design process, *Design Stud*, **21(6)** (2000) 539–567, [https://doi.org/10.1016/S0142-694X\(99\)00034-4](https://doi.org/10.1016/S0142-694X(99)00034-4).
- Lightsey B, *Systems Engineering Fundamentals* (Fort Belvoir, Virginia: Defense Acquisition University Press) 2001.
- Prasad Y & Saha S K, Development of an AC motor powered device for making tulsi mala beads, in *Rural Technology Development and Delivery* (Springer Nature Singapore) 2022, 21–28.
- Choudhary S K, Ethnobotany and the Sacred Divine Plant: Tulsi, *Res Rev J*, **5(9)** (2020) 242–244, <https://doi.org/10.31305/rrijm.2020.v05.i09.059>.
- Gupta R. K, Sharma M, Singh D P, Suthar B & Saha S K, Women empowerment by technology supported manufacturing of beads from Holy Basil, *Curr Sci*, 2015, 1660–1664.
- HIWIN, Linear Guideways MG Series, (2022) <http://motioncontrolsystems.hiwin.us/Asset/MG-Series-Catalog.pdf>. (15 January 2023).
- Hart S L, *Capitalism at the Crossroads: The Unlimited Business Opportunities in Solving the World's most Difficult Problems*, (Pearson Education) 2005.
- Bhattacharjya B R & Kakoty S K, An exploration of intermediary's role in participatory product design at the bottom of the pyramid: the case of improvised Pedal-Operated Chaak, *J Mech Design*, **142(12)** (2020) 124501.
- Junior J D C, Diehl J C & Snelders D, A framework for a systems design approach to complex societal problems, *Design Sci*, **5** (2019) e2, doi: 10.1017/dsj.2018.16.
- IDEO.org, *The Field Guide to Human-Centered Design*, 2015.
- UNEP, Design for Sustainability: A Step-by-Step Approach, (2009) <https://wedocs.unep.org/20.500.11822/8742> (10 July 2023).
- Tickoo S, Creo Parametric 4.0 for Designers (CADCIM Technologies) 2017.
- Stamatis D H, *Failure Mode and Effect Analysis: FMEA from Theory to Execution* (Quality Press) 2003.
- Castillo L G, Diehl J C & Brezet J C, Design Considerations for Base of the Pyramid (BoP) Projects, in *Proc Northern World Mandate: Culumus Helsinki Conference 2012*, 24–26.
- Mattson C A & Wood A E, Nine principles for design for the developing world as derived from the engineering literature, *J Mech Design*, **136(12)** (2014) 121403, doi: 10.1115/1.4027984.
- NIH, It's a Noisy Planet. Protect Their Hearing. (2019) <https://www.noisyplanet.nidcd.nih.gov/parents/too-loud-too-long>. (10 January 2023).

- 26 Jansen A & Slob P, Human Power; Comfortable One-Hand Cranking, in *DS 31: Proc ICED 03, 14th Int Conf Eng Design* (Stockholm) 2003.
- 27 Pugh S, Concept Selection: A method that works, in *Proc Int conf Eng Design*, 1981, 497–506.
- 28 Misumi, Selection of timing belts1, (2018) <https://us.misumi-ec.com/pdf/fa/2010/p3515-3536.pdf>, (29 March 2023).
- 29 Budynas R G & Nisbett J K, *Shigley's Mechanical Engineering Design*, **10th edn**, (McGraw Hill Education (India) Private Limited) 2016, 360.
- 30 Rao S S, *Mechanical Vibrations* (New York: Addison-Wesley) 2001.
- 31 Precision Bearing House, Solutions for Industrial Automation, (2020) <https://www.pbh.in/shop/mcs-12-length-1000mm-61462?category=13#attr=> (29 May 2023).