Computational Support to Design and Fabrication of Traditional Indian Jewelry

Vineet K. Goel[1], Dinesh Khanduja[2], T.K. Garg[3] and Puneet Tandon[4]

[1]National Institute of Technology, Kurukshetra, India, vineet13ss@rediffmail.com
[2]National Institute of Technology, Kurukshetra, India, dineshkhanduja@yahoo.com
[3]National Institute of Technology, Kurukshetra, India, tkgargnitk@yahoo.com
[4]PDPM Indian Institute of Information Technology, India, ptandon@iiitdmj.ac.in

ABSTRACT

This manuscript presents an approach to recreate traditional Indian ornamental designs and a schema to innovate the designs due to new interpretations of the traditional styles using Computer Aided Geometric Modeling. The ornamental patterns are ideally suited to computer-controlled manufacturing that can build real world artifacts from synthetic computer descriptions. The primary objective of the work is to develop mathematical models and algorithms to provide computational support to the design of traditional Indian jewelry and in the process simplifying the design methodology of complex traditional ornamental designs. The work also makes an attempt to incorporate artistic sense, traditional touch and imagination in the designs. The work is based on pattern design methods. A profile is used as the basic sketch for pattern design. A cluster is made up of profiles and the cluster type depends on the profile arrangements. For jewelry design, the patterns are implemented on the user-defined surfaces by parametric feature based technique and bubble-packing technique. Finally, the prototype is generated through RP machine by taking the output in .STL format from the software.

Keywords: geometric modeling, pattern design, traditional jewelry, bubble packing technique.

1. INTRODUCTION

To enhance their God-gifted beauty, humans added ornamental support. Later, jewels were also added to the natural beauty of the human being. The proficiency of artisans that demonstrate affluence, supremacy and profusion of the prosperous legacy of jewelry has been represented by Asian continent, especially India, since time immemorial. The history of more than 5000 years shows that the Indian jewelries established as a highly desired and demanded product. Initially it was sought by the effluent chosen ones only, but currently it has become almost a necessity for a large segment of masses, that cover people not only of both the sexes but of wide age groups also. The usage of jewelry started from the local gods and goddesses, and then spread to kingdoms, films, dance costumes, etc. Indian jewelry includes one class that is called ethnic jewelry. This form of jewelry has changed a lot with time. The ethnic jewelry can be categorized into traditional, medieval and 19^{th} century modern forms. The broad spectrum of aesthetic designs emerged with the changing dynasties and reflected the diversity of culture, denizens tastes, and the artistry of the designers. The characteristics of each era were different and unique with change of time. The jewelry evolved with material form (from stones to metals),designs refinements, weight reduction, variables in usages, body organs, etc. The current era includes primarily gold, silver and diamond jewelry. In earlier days, no one would have even thought that the jewelry making would emerge as an engineering process involving standard quality of materials, and standardization on global quality parameters. The list of traditional Indian jewelry includes crowns, necklaces, pendants, rings, bangles, kadas, pajebs, bracelets, tikas, earrings, chains, anklets, etc.

A large number of parametric and feature based systems have been developed for jewelry design with excellent rendering capabilities. Such tools are being used for artistic and aesthetic applications. In these applications, the aim is not only to realize certain geometries and patterns but also to achieve overall aesthetic appeal. For this purpose, examples are present in [14,15], where parametric patterns generated are implemented to create and modify artifacts. A survey on CAD methods used in another aspect of artistic expression, i.e. garment design, is provided in [10, 13]. Jewelry design is another example of combining CAD tools and traditional designs. A few software tools have been developed for designing and creating CAD jewelry models such as ArtCAM, Jewel Smith, Delcam Designer, Rhinoceros, Matrix 3D jewelry design software, Jewel CAD [7] and Jewel Space[8].Besides, majority of these systems have the competence to export the CAD models of jewelry to additive manufacturing (AM) machines.

Stamati et al. [18,19] introduced Byzantine CAD, a parametric CAD system for the design of pierced medieval jewelry. Byzantine-CAD is an automated, parametric CAD system for designing and producing pierced Byzantine jewelry where the user-designer sets some parameter values and Byzantine-CAD creates the jewelry model that corresponds to the specified values. A parametric approach to create carved jewelry is also presented in [6].

Most of the jewelry manufacturers use traditional methods for jewelry design and fabrication. The elements of ornamental designs can be categorized into, based on (a) geometrical elements (both analytical and synthetic) such as line, curve, circle, polygon; (b) nature e.g. plants, star and (c) artificial objects like shields, ribbons, etc. The primary objective of this work is to propose a computer supported geometric modeling schema to help develop traditional Indian ornamental designs. The goal of the work is to automate the generation of user specific designs of traditional Indian jewelry in a convenient manner; and their quick and easy fabrication. The work involves development of mathematical models and algorithms that can develop novel yet traditional Indian ornamental designs and in the process simplify their design process. The proposed approach can improve design and fabrication of ornaments, particularly repeatable products like ornamental jewelry. The objective also includes reducing the dependence on formal designers and providing the design tool in the hand of users by enabling them to generate a large number of traditional designs as per their preference.

This work is further directed towards incorporating artistic and traditional sense and imagination into the design tool so as to facilitate even the persons having least imaginative and artistic skills to design designer jewelry [21]. The design tool and AM technology can improve the efficiency as well as productivity of the jewel-smiths. These tools would be effective in significantly shrinking the effort and time required for designing and creating ornamental products [5].

The specific aims of this work are:

- To uplift the design process of traditional Indian jewelry and make an effort to implement the designs through CAD/CAM tools instead of manual design and fabrication.
- To evolve a jewelry design and manufacturing methodology that can reduce cost, improve quality, maintain the traditional and aesthetic values, and improve productivity.
- To model mathematically the semantics of jewelry designs so as to create clusters and ultimately the traditional patterns for ornamental products like bangle, ring, necklace, pendent, earring, etc.

2. METHODOLOGY

In working with the shapes, whether artistic or mathematical, it is necessary to find how complex shapes can be derived from the simple ones. The self-similar geometric patterns are characterized by primary repetitive geometric patterns and with reduced scale secondary geometric patterns [2, 17]. Symmetry is one of the most important properties of a shape, unifying form and function [1]. It encodes semantic information on one hand, and affects the shape's aesthetic value on the other. Continuous intrinsic symmetries can be represented using infinitesimal rigid transformations, which are given as tangent vector fields on the surface [3,4]. The semantic units are defined and classified into five categories for ease of understanding [20]. Classification is based on basic geometric shape or resemblance. Shapes of semantic unit are classified as one axis asymmetry, two axis symmetry, rotational symmetry, sphenoid and conjoined. Tab. 1 presents the shapes of a few semantic units.

As a first step, different profiles are created in line with the ancient traditional Indian Jewelery designs and they are differentiated based on their shapes and usage; like Jau, Chand, Heart and Bund (Fig. 1). The profile consists of line, circle, arc, etc., whose behavior is controlled by geometrical and dimensional constraints. Geometrical constraints are applied on the unit and these constraints are further used to define the relationship between two entities as collinear concentric, equal length, equal radius, as well as midpoint, tangent and vertical align. These constraints are applied as per the profile development requirement. The profiles are created using the parametric equations. Parametric equations for profiles of different form are as shown below:

1. Heart

$$\begin{cases} p_x(\theta,t) = x_c + 16a * \sin^3(\theta), \theta \in [0,\pi/2] \\ p_y(\theta,t) = y_c + a(13\cos(\theta) - 5\cos(2t) \\ \qquad\qquad - 2\cos(3\theta) - \cos(4\theta)) \\ p_z(\theta,t) = z_c + t * H, \quad t \in [0,1] \end{cases}$$

2. GoleTrikon

$$\begin{aligned} \text{Arc1}: \quad & p_x(\theta,t) = x_{1c} + r\cos(\theta) \quad \theta \in [0, 2\pi/3] \\ & p_y(\theta,t) = y_{1c} + r\sin(\theta) \\ & p_z(\theta,t) = z_c + t * H \qquad t \in [0,1] \end{aligned}$$

S.No	Shape	Semantic Unit	Description	Classification
1.		Heart	Heart/ Pan shape	Symmetric about one axis
2.		TikhaPyala	Cup shape	Symmetric about one axis
3.		TikhiChoki	Square with concave curve	Symmetric about two axis
4.		GoleChofuliya	A circular floral motif with four petals	Symmetric about two axis
5.		Teda Chand	Tilted half-moon shape	C Shape-Sphenoid
6.		KhanchKoyali	Stylized koyali with one side notch	N Shape-Sphenoid
7.		Ful	A highly stylized flower blossoming	Conjoined
8.		Chidi Patti	A shape like a club in cards, with one lobe having an apex	Conjoined

Tab. 1: Semantic units used for jewelry design.

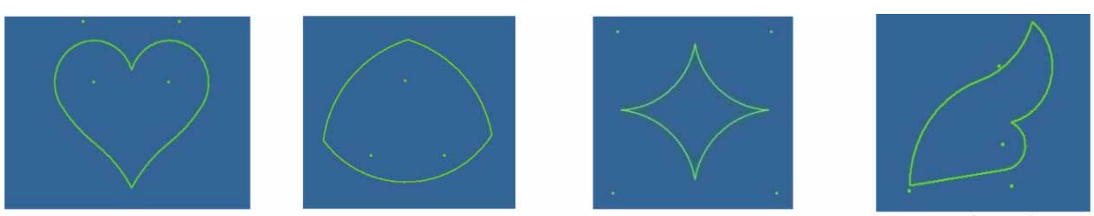


Fig. 1: Shapes of different Profiles.

$$\text{Arc2}: \begin{array}{ll} p_x(\theta,t) = x_{2c} + r\cos(\theta) & \theta \in [2\pi/3, 4\pi/3] \\ p_y(\theta,t) = y_{2c} + r\sin(\theta) & \\ p_z(\theta,t) = z_c + t*H & t \in [0,1] \end{array}$$

$$\text{Arc3}: \begin{array}{ll} p_x(\theta,t) = x_{3c} + r\cos(\theta) & \theta \in [4\pi/3, 2\pi] \\ p_y(\theta,t) = y_{3c} + r\sin(\theta) & \\ p_z(\theta,t) = z_c + t*H & t \in [0,1] \end{array}$$

$$\text{Arc3}: \begin{array}{ll} p_x(\theta,t) = x_{3c} + r\cos(\theta) & \theta \in [\pi, 3\pi/2] \\ p_y(\theta,t) = y_{3c} + r\sin(\theta) & \\ p_z(\theta,t) = z_c + t*H & t \in [0,1] \end{array}$$

$$\text{Arc4}: \begin{array}{ll} p_x(\theta,t) = x_{4c} + r\cos(\theta) & \theta \in [3\pi/2, 2\pi] \\ p_y(\theta,t) = y_{4c} + r\sin(\theta) & \\ p_z(\theta,t) = z_c + t*H & t \in [0,1] \end{array}$$

3. TikhiChoki:

$$\text{Arc1}: \begin{array}{ll} p_x(\theta,t) = x_{1c} + r\cos(\theta) & \theta \in [0, \pi/2] \\ p_y(\theta,t) = y_{1c} + r\sin(\theta) & \\ p_z(\theta,t) = z_c + t*H & t \in [0,1] \end{array}$$

$$\text{Arc2}: \begin{array}{ll} p_x(\theta,t) = x_{2c} + r\cos(\theta) & \theta \in [\pi/2, \pi] \\ p_y(\theta,t) = y_{2c} + r\sin(\theta) & \\ p_z(\theta,t) = z_c + t*H & t \in [0,1] \end{array}$$

4. KhanchKoyali:

$$\text{Line1}: \begin{array}{ll} p_x(S,t) = x_1 + [x_2 - x_1]*S & S \in [0,1] \\ p_y(S,t) = y_1 + [y_2 - y_1]*S & \\ p_z(S,t) = z_c + t*H & t \in [0,1] \end{array}$$

$$\text{Arc1}: \begin{array}{ll} p_x(\theta,t) = x_{1c} + r\cos(\theta) & \theta \in [0, \pi/2] \\ p_y(\theta,t) = y_{1c} + r\sin(\theta) & \\ p_z(\theta,t) = z_c + t*H & t \in [0,1] \end{array}$$

$$\begin{aligned}\text{Arc2}: \quad & p_x(\theta,t) = x_{2c} + r\cos(\theta) && \theta \in [\pi/2, \pi]\\ & p_y(\theta,t) = y_{2c} + r\sin(\theta) \\ & p_z(\theta,t) = z_c + t * H && t \in [0,1]\end{aligned}$$

$$\begin{aligned}\text{Arc3}: \quad & p_x(\theta,t) = x_{3c} + r\cos(\theta) && \theta \in [\pi, 3\pi/2]\\ & p_y(\theta,t) = y_{3c} + r\sin(\theta) \\ & p_z(\theta,t) = z_c + t * H && t \in [0,1]\end{aligned}$$

$$\begin{aligned}\text{Arc4}: \quad & p_x(\theta,t) = x_{4c} + r\cos(\theta) && \theta \in [3\pi/2, 2\pi]\\ & p_y(\theta,t) = y_{4c} + r\sin(\theta) \\ & p_z(\theta,t) = z_c + t * H && t \in [0,1]\end{aligned}$$

After creation of profiles, in the second step, combinations of different profiles are arranged in certain orders to form the clusters (circular cluster and rectangular cluster). After the formation of a cluster, the next step is pattern formations. Patterns are generated on both, two-dimensional or three-dimensional surfaces. The pattern creation is of three types' i.e. rectangular pattern, circular pattern and curve driven pattern. The main phase in the process of jewelry design is to implement these patterns on the ornament surfaces. In this process, parametric feature based technique and bubble-packing technique are used, as described below. Finally, the prototype is generated through AM machine by taking the output in .STL format from the jewelry design tool. This design tool can be implemented on plane, cylindrical and three-dimensional surfaces.

2.1. Parametric Feature Based Technique

The term parameter includes dimensional parameters, location parameters and associated constraints. Making changes to the parameters and reevaluating the constraints and relations can easily create new models [12]. Surfaces are mathematically represented explicitly, implicitly or parametrically. This technique is applied to generate patterns on the parametric surfaces. Parametric space of the selected face is used in this method. The Autodesk Inventor API is used to find the parametric bounding box of the face. The user provides the number of instances in u direction as well as in v direction, which are further used to find the points in parametric space. The parametric points are mapped in the object space to get three-dimensional (3D) points. These 3D points are used to locate the new surface bodies on selected face. Patterns are created parametrically on these 3D surfaces. Fig. 2 shows the stepwise design process for parametric feature based technique.

2.2. Bubble-Packing Technique

The bubble-packing method based upon the physical concept of packing bubbles inside a given domain has been introduced as a promising technique for geometric modeling [11,16]. In this method, bubbles move in a domain until forces between bubbles are stabilized, and the Delaunay triangulation is then applied to generate a mesh connecting the nodes defined by the bubble packing [9]. The parametric bounding box of the surface and 3DCartesian space is used to determine optimum feature positions. Bubbles are packed on geometric entities namely points, curves, and surfaces in ascending order of dimension. These geometric entities are corresponding to vertices, edges, and faces, respectively. It then defines Vander-Waals like forces between bubbles. With inter-bubble force, two adjacent bubbles attract each other when they are too far separated, and drive apiece away when too imminent. This leads to a tightly packed, force-balanced configuration of bubbles, which usually is a continuance hexagonal arrangement, a pattern often, attimes observed in nature. The main steps of bubble-packing technique are:

- Hierarchical spatial subdivision
- Inter-bubble forces
- Physically based relaxation

Stepwise design process for bubble-packing technique is shown in Fig. 3.

The proposed approach creates unique kinds of ornamental patterns, which are not possible to design with the existing commercial systems. The presented approach can produce a large number of ornamental designs by changing the modeled profiles and their arrangements. These ornamental designs contain circular and rectangular symmetry. Optimization techniques are used in bubble surface patterns. They adapt to the curvature, optimizing the bubble placement on the surface region of high curvature with small size bubbles and a region of low curvature with larger size bubbles. Through smoothing technique bubbles are packed with in the boundary conditions and restricted to move out of the target region. Thus, each bubble is kept inside the target domain.

Boolean operations are involved in a feature instantiation or modification. This is the last step of pattern design. The Boolean is performed between base surface body and new surface bodies, which are present at the bubble location. Boolean unite and Boolean subtraction are used to add new surface bodies to the base surface body and to subtract new surface bodies from the base surface body. There for basic shapes having a linear thickness variation.

3. IMPLEMENTATION

The proposed work is implemented in Autodesk Inventor through its Application Programming Interface (API).For traditional jewelry design and manufacturing, a design modeler is developed as add-on inside Autodesk Inventor. Add-ons are a set of programs that can interact with Inventor API either as in process or as stand-alone program (external-process to Inventor). The aim of this jewelry add-on is to develop three-dimensional thin patterns of traditional jewelry

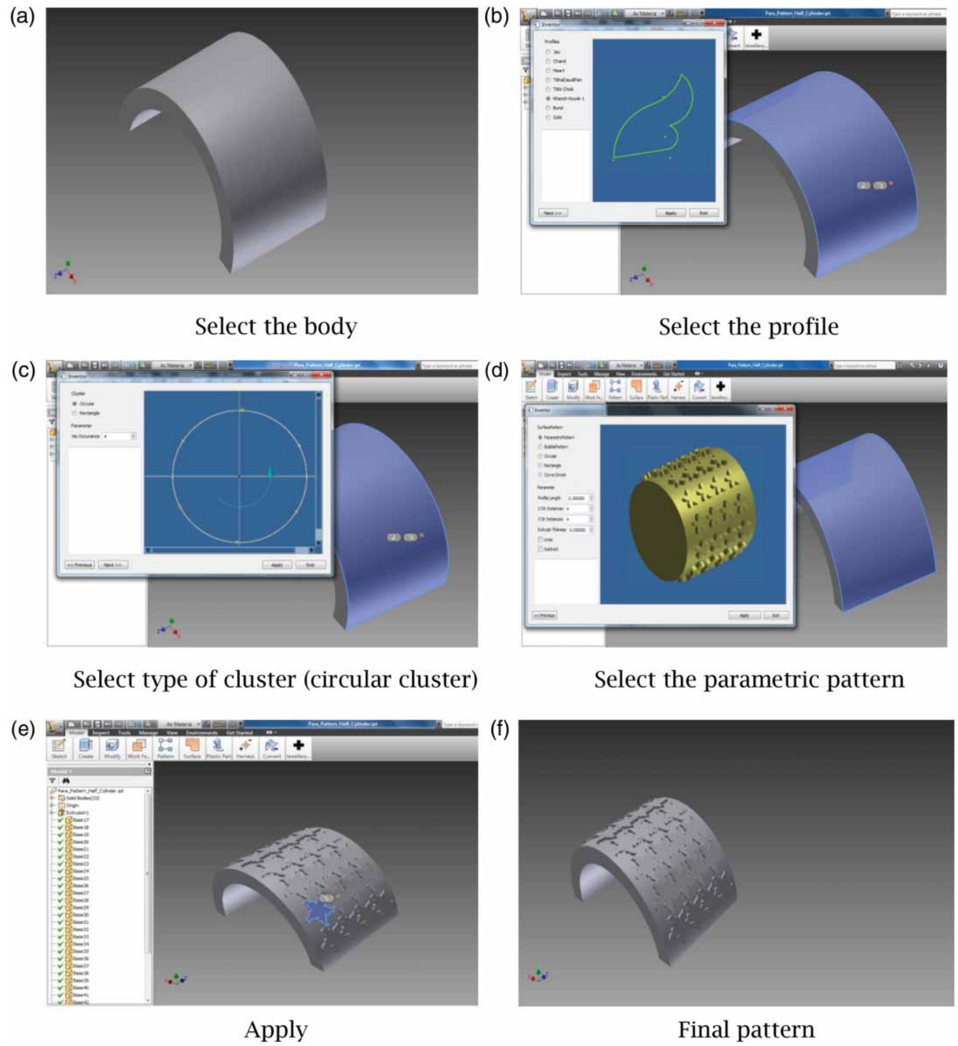


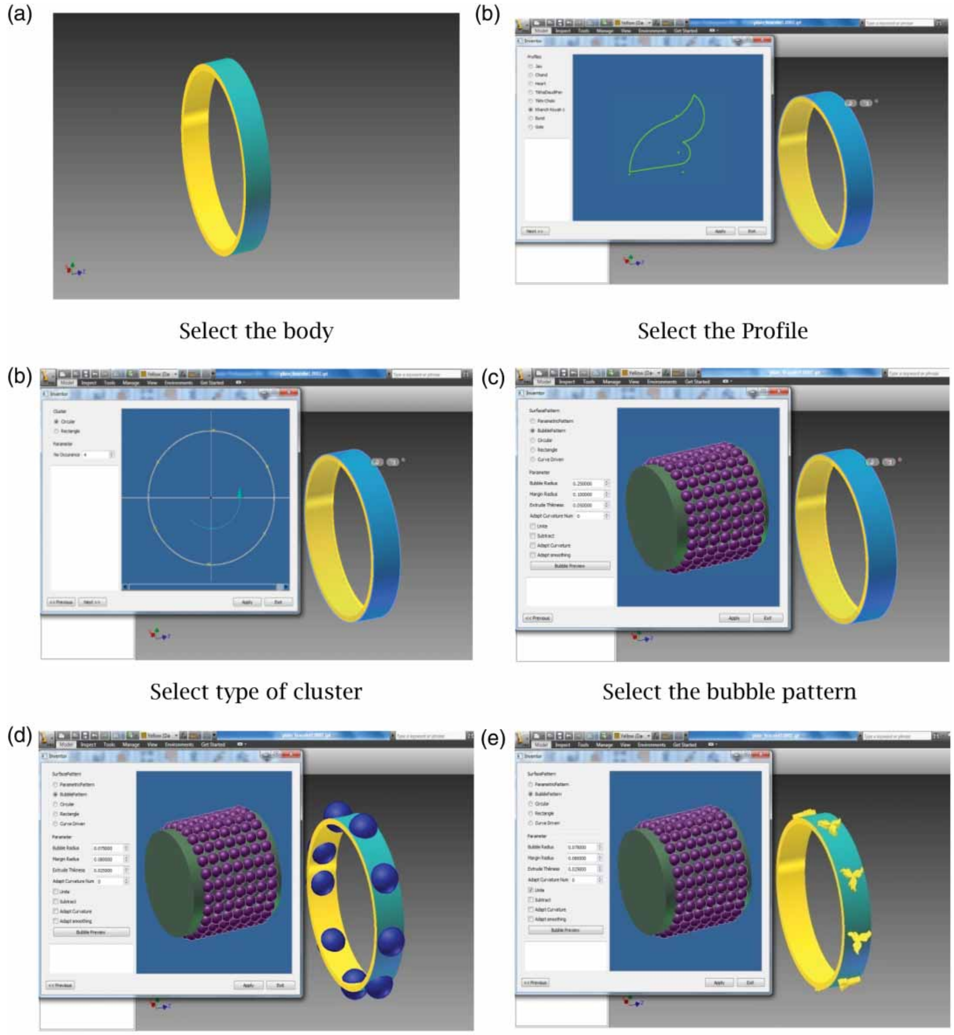
Fig. 2: Stepwise design processes for parametric feature based technique.

on the surfaces. The add-on uses parametric design based concepts that provide a large variation in the designs. This work has been validated by fabricating the rendered traditional jewelry designs by AM process. An STL file is created that can be transmitted to AM machine for fabricating jewelry designs.

4. RESULT AND VALIDATION

Stepwise design process for parametric feature based technique is shown in Fig. 2 and for bubble-packing techniques is presented in Fig. 3. The modeler is automated and easy to use. The user interactions are turned into solid three-dimensional models to create design models of his/her choice. The proposed approach creates a unique kind of traditional patterns on jewelry products, which is not possible to design with the existing commercial systems. The present approach can produce a large number of Jewelry designs by changing the modeled the type of profiles and their arrangements.

The work proposes a new dimension to the field of jewelry design to improve its fabrication. The work has brought out different aesthetic results for traditional ornamental deigns. The proposed approach creates unique traditional Indian ornamental designs for jewelry and produces a number of jewelry products as shown in Fig. 4, which seems to be not possible with the existing commercial systems. The designs created for traditional Indian ornamental products have been checked for their validation by creating 3D design elements in CAD modeler and the result has been generated through layered manufacturing techniques (LMT). A few rendered and LMT models are shown in Fig. 5. Standardization as well as automation has been achieved in the work through the integration of CAD-CAM tools.



(a) Select the body

(b) Select the Profile

(b) Select type of cluster

(c) Select the bubble pattern

(d) Apply

(e) Parametric bubble patterns

Fig. 3: Stepwise process for bubble-packing technique. (KhanchKoyali Profile with circular cluster and rectangular pattern).

(a) Design with circular cluster and 3 numbers of Kanch Koyali Profile

(b) Design with circular cluster and 4 numbersof Kanch Koyali Profile

(c) Design with circular cluster and 3 numbers of Heart Profile

Fig. 4: Unique kind of traditional Indian patterns on jewelry products like bracelets.

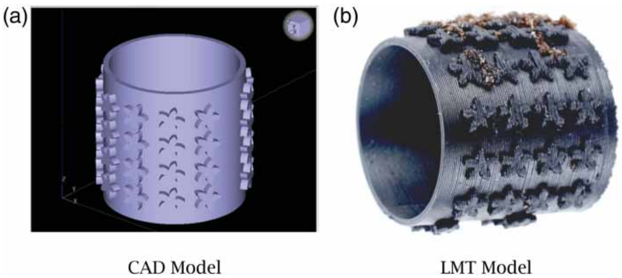


Fig. 5: Pattern on cylindrical surface, (a) CAD model and (b) fabricated model.

5. CONCLUSIONS

This work aims at exploring the possibility of using modern mathematical and computer aided design tools to develop new ways of designing and manufacturing the traditional Indian ornamental designs. Most of the ornamental products are non-functional, but of aesthetic importance, because they strongly influence emotions of the human beings. They also enhance the attractiveness of human beings. Such attributes are expressed via different forms of ornamental patterns. The goal of producing different forms of traditional Indian ornamental designs has been achieved concisely and unambiguously in this work through Computer Aided Geometrical Modeling schema in a unified manner. The ornamental designs are generated in the form of patterns on the 2D / 3D surfaces of the ornaments. Patterns are generated in the form of clusters, which in turn are different combinations of various profiles. The profiles developed in this work are inspired by traditional Indian jewelries.

The design and manufacturing tools allow us to simplify the iterative design process and facilitate modeling of jewelry products of any shape, type and size. They also help in shortening the required time for making models and hence, reduce the overall production time. Ornamental patterns rapidly change their styles. Besides, innovations and improvements in design and manufacturing are occurring on a routine basis. The use of the proposed design tools can improve productivity, manufacturability, integrity and repeatability of ornamental products.

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