





A Knowledge-Based CAD Modeling Paradigm for Indian Traditional Filigree Jewelry

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Abstract. The present work aims to develop a knowledge-based parametric CAD modeling system to create Indian traditional filigree jewelry designs. Today, developments in CAD technologies are towards reducing the time and efforts of designers required in modeling. Indian traditional Filigree jewelry is delicate metal craftwork representing twisting or curling of pliable wire and shows the beauty of local craftsmen's traditional workmanship involved in making this type of decorative embellishments that result in a very precise and delicate model. Traditional craftworks involve much skill, effort, and time, so upcoming generations are not interested in their respective traditional works. The traditional knowledge base of Filigree jewelry is incorporated in the CAD system's programming environment by defining some shape grammar rules and logical rules to control jewelry attributes. Parametric modeling has great potential to develop customized CAD tools for automation in generating 3D models of handicraft products in a virtual environment. By using knowledge base rules, geometrical models can be designed beyond a conventional design. This knowledge-based jewelry modeler is developed using the Microsoft Visual Basic Programming environment in SolidWorks API.

Keywords: Parametric Modeling, SolidWorks API, Knowledge-Based Modeling, Indian Traditional Jewelry.

DOI: <https://doi.org/10.14733/cadaps.2022.207-219>

1 INTRODUCTION

Traditionally, the Indian jewelry designing process involves two specialized tasks: drawing-by-hand and manufacture-by-casting. These tasks are regarded as ancient traditions passed on through generations. These tasks involve much skill, effort, and time, so upcoming generations of jewelry makers are not interested in their respective traditional works. They feel a lot of anxiety due to the growing expectations in terms of novelty in designs and high-quality jewelry. Their lack of indigenous knowledge in this craft sector has let down the interest in producing traditional jewelry. As a result, the traditional jewelry business is at the edge of fall down.

Traditional jewelry designing depends on craftsman experience and artistic sense. The innovation of jewelry designs requires expertise, particularly generating new design ideas. As jewelry designing is inherently a knowledge-intensive activity, a great deal of emphasis is needed to use its knowledge base in computer-aided design [2]. But, it is realized that there is often reluctance among jewelry makers to embrace the CAD/CAM technology because of fear of losing their heritage style of craftworks. Consequently, in this work, an idea of convergence of craftwork and technology has been implemented in jewelry making as a fusion of computer-aided jewelry designing with traditional manufacturing by casting. The craft people are CAD illiterate persons. Therefore, an interactive and user-friendly Graphical User Interface (GUI) is needed to develop in a CAD programming environment that accepts craftsmen's data input and interacts with CAD software.

The present work aims to develop a CAD tool to produce Indian traditional filigree jewelry designs using knowledge-based parametric CAD modeling. A knowledge-based approach encourages the virtual jewelry designing to provide parametric and dynamic modeling through which geometric manipulations can be carried out to alter designs in a CAD system. This will help to cut down the jewelry designing time and as well as production cost. Furthermore, this system provides a way to automate craftsmanship and extend CAD system features to use it beyond limits. Such CAD customization supports the creative jewelry design process and allows the designer to create novel 2D and 3D virtual designs; to prolong this Indian jewelry sector.

The jewelry knowledge base is a repository of rules, theory, assumptions, regulations, concepts, details, etc., and these rules can generate geometric models in a more flexible and controlled system. Traditional knowledge base, which captures the jewelry design attributes and process information, is programmed in CAD environment so that it can be retrieved whenever required. The automatic jewelry CAD model generation is carried out with a predefined framework that utilizes craft knowledge, traditional artistic sense in design computations, and parametric modeling in CAD. Visual Basic for Application is employed in SolidWorks customization to perform parametric modeling and the macro codes to generate the jewelry CAD models.

2 RELATED WORK

Today, developments in CAD technologies reforming the jewelry designing process and several industry-specific CAD software's are available in the market for jewelry modeling to create jewelry masterpieces [1], [11], [14], [18]. These systems provide advanced features in modeling and rendering of some common types of jewelry (such as earrings, rings, bracelets, necklaces, cufflinks, etc.) with gems and relief settings. All the commercial CAD systems are capable of converting CAD models into RP models. Traditional pieces of jewelry are significant due to the technical perception involved in the jewelry making process and the presence of a well-developed artistic sense. Traditional crafts are the results of continuous improvement and innovations by local craftsman's with aesthetic beauty. In traditional craft products, the major difficulty is understanding of nature and characteristics of designs [10]. Recently, jewelry designers incorporate techniques based on craftsmanship, like fine art, decorative art, and applied art [7]. Handicraft designing using modern CAD tools requires much more skills other than traditional knowledge [24]. The task of jewelry designing through these CAD systems can only be performed when jewelry makers have expertise in the inherent mathematical mechanism of these systems as the modeling is based on geometrical transformations [16]. Since most traditional jewelry makers are novice CAD users, they are not proficient in designing with CAD. Consequently, these conventional CAD systems are not finding themselves successful in impacting the Indian traditional jewelry sector.

Because of the above fact, some customized jewelry CAD tools in which a set of jewelry modeling steps are incorporated programmatically by customizing a CAD system. A CAD modeler is developed to produce forming tools using parametric voxels for stretch-formed jewelry in which design patterns are embossed on thin metal sheets [8]. The voxels are placed in different positions as per the jewelry design required. In the traditional craftwork, the freehand sketching is an inherent

element in design and enables visualization of idea using pencil and paper. In WrapIt, the input line drawings are decomposed into small smooth segments of curves and jigs are printed to assist novice users in bending and wrapping of wires [9]. The Sketch2Jewelry [23] is sketch-based modeling CAD tool which retrieves feature based on sketch data and some procedural rules are applied to compute shape/curve parameters. A parametric feature-based CAD interface is developed for the design of traditional pierced jewelry, which is termed as ByzantineCAD [19]. Structural elements are parameterized as a shape of rectangular parallelepiped with carving around a hole and the user participation is limited to input elements parameter. Fractal constructing Iterative Function System is utilized to generate ring and jewelry designs by using motif curve as fractal geometry [20], [22]. The fractal curve gives a new aesthetic to the ornamental products. However, these tools would not produce traditional jewelry masterpieces for jewelry makers who are CAD illiterate for facilitating their design work.

It is revealed that these customized jewelry CAD tools may not be the whole substitute for jewelry designing for inexperienced jewelry makers who do not have artistic talent in their field. Even after getting knowledge of utilizing these customized CAD tools, unskilled jewelry makers would not be able to produce pleasing jewelry designs as jewelry making is a field that still largely relies on individual skills. Using interactive 3D modeling, the designer can re-construct sculptures surfaces from unstructured or ambiguous data by parameterization of model data [3]. Computer helps in shape optimization and various simulations to evaluate the model as sound from aesthetic as well as technical [17]. Parametric modeling and knowledge base systems [16] have great potential to develop customized CAD tools for automation in generating 3D jewelry models in a virtual environment [4], [12]. The knowledge base system captures the design attributes and process information of a model to support decision making in design process. This work targets a different group of novice crafters interested in incorporating CAD tools in designing their unique jewelry with hands-on manufacturing techniques.

3 PARAMETRIC MODELING IN JEWELRY

Recent developments in techniques, such as digital tools and modern techniques in jewelry manufacturing have encouraged researchers to study the industry's features. In modern CAD systems, the basic structural elements are defined through the parametric definition and some specific attributes are applied in the modeling of complex jewelry designs [5]. Most commercial CAD packages use the parametric design concept and have a characteristic: the geometric changes are made by controlling the variables [15], and from a single motif, it is possible to make endless variations to the shape.

All over the world, the peoples choose the jewelry products having the traditional appearance and these traditions have certain motifs. The designs are created by the artistic imaginations of jewelry makers. Due to design and motif variation in traditional designs, the CAD software available is unsuitable for traditional jewelry designs. In traditional jewelry designing, using parametric design methods, new jewelry designs can be prepared with new textures and forms, increasing modernization [16]. Today, personalized products are more preferred by peoples, which are also fulfilled by parametric jewelry modeling.

4 A KNOWLEDGE-BASED MODELING APPROACH FOR FILIGREE JEWELRY

Filigree jewelry is famous in Orissa and Andhra Pradesh states of India. It is a delicate craftwork representing the twisting of wire threads, usually of gold, silver, and aluminum, into a design. Traditionally, a twisted wire strand is created by twisting two or three plain wires together. Further, twisted wire strand is crimped into a motif (usually have geometries like jails, curls, cycloids, spirals, etc.), filled in a frame (usually made of single wire and with a theme like leaves, rosettes, flowers, animals, especially butterflies and birds) and endowed by soldering with frame (shown in Fig. 1).



Figure 1: Traditional Filigree Jewelry.

One of the knowledge base of filigree jewelry is to identify the motifs used in this jewelry tradition. By exploring the designs of filigree jewelry in India, more than ninety types of motifs are identified. These traditional motif geometries have been defined in terms of parametric mathematical equations in a CAD system's programming environment (Fig.2).

Further, it is revealed, particularly from those designs created by local craftsmen, a number of basic shaped motifs are joined into an intricate shape that is being inserted repeatedly into a frame in every ancient jewelry design. The knowledge base here is to get how multiple motifs could be joined to produce compound-motifs. The attribute of this knowledge base is to find number, size, and orientation of motifs with respect to frame.



Figure 2: Primary Motifs Shapes of Filigree Jewelry.

Another knowledge base of filigree jewelry is to find how multiple motifs/compound-motifs could be symmetrically placed and joined as a jewelry design (floral, peacock, rosettes, animals and birds, etc.). One of the attributes of this knowledge base is to get the number and size of motifs/compound-motifs to get geometrical symmetry. Another attribute of the knowledge base is to get jewelry size so that multiple motifs/compound-motifs bounded remains in contact with the frame.

All traditional knowledge base is incorporated in the CAD system's programming environment by defining some shape grammar rules and logical rules to control these attributes. Such an integration of traditional knowledge base and CAD customization acknowledges the jewelry design automation. The defined motifs/compound-motifs can be parametrically controlled through a user interface and programmatically interaction in the CAD system. This enables the user to interact with the modeling environment through the interface to get variety in geometric designs.

This CAD paradigm has been implemented in Solidworks application programming interface, which utilizes predefined native CAD entities (point, line, circle, spline, etc.) and operations (extrusion, revolution, sweep, etc.) with the specific algorithm. The algorithm includes modeling

steps from sketching to feature-based operations to generate the desired jewelry designs in a Visual Basic programming environment. A set of jewelry modeling steps are incorporated programmatically by customizing a CAD system are presented.

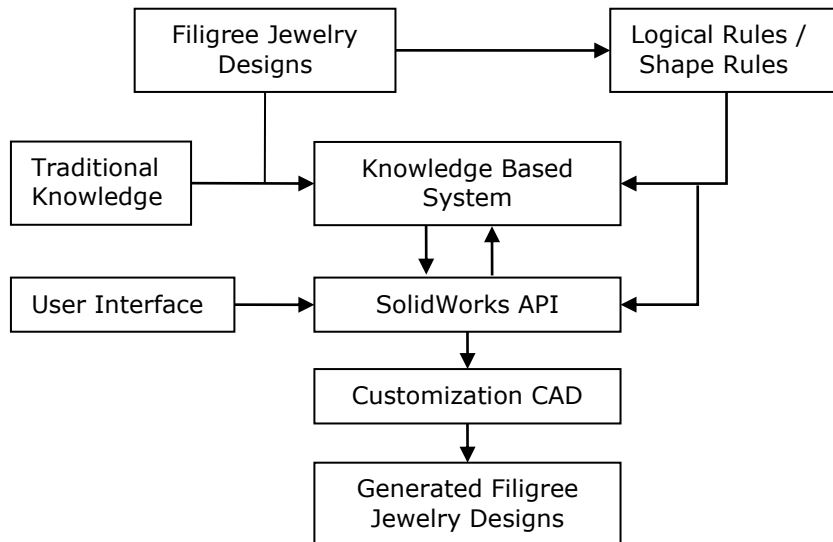


Figure 3: A knowledge-based modeling approach for Filigree Jewelry.

5 PARAMETRIC MATHEMATICAL DEFINITIONS FOR MOTIF GEOMETRIES

The geometry of motifs is in the form of a planar map created by simple curves and lines and can be defined parametrically by a set of point coordinates. Motif geometries used in Filigree jewelry designing are programmed in the CAD system by parametric mathematical definitions to implement the concept of parametric modeling which enables user to alter the motif shapes with the change in mathematical parameters. This sort of coordinate geometry information is fundamental to the motif's primary position in Filigree jewelry design work.

Parametric mathematical definitions of spiral shaped motif, heart shaped motif, pear shaped and teardrop shaped motif which are most commonly used geometries in Filigree jewelry designs (as shown in Figure 1) are represented in table 1.

As an example, a parametric Archimedean spiral-shaped motif in a two-dimensional plane is described mathematically as:

$$x = rt \cos(n\theta) \quad y = rt \sin(n\theta) \quad t = 0,1 \quad (1)$$

Parameters that affect the geometry of Archimedean spiral are r , n , t , and θ . The r is the radius of the circumscribed circle to which n turns of spiral are placed at a fixed space between turns. The value θ varies from 0 to 2π for a complete turn.

The modeling of these shapes using parametric definitions is carried out by defining functions in Solidworks API in the VBA programming environment. Many functions and procedures are called in the programming environment to generate the sketch of the shape required in a parametric way. For Archimedean spiral (Figure 4), the VBA function is:

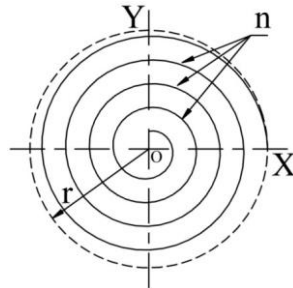


Figure 4: Archimedean spiral-shaped motif geometry.

Name of Motif Element	Parametric Definition of Geometry and Geometric Shape Parameters	Jewelry Motif
Ring Motif	$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} r \cos(t) \\ r \sin(t) \end{bmatrix}$ <p>r - Radius of Ring, t - 0 1</p>	
Oval shaped Motif	$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} a \cos(t) \\ b \sin(t) \end{bmatrix}$ <p>a - Major Axis, b - Minor Axis, t - $0, 2\pi$</p>	
Archimedean Spiral Motif	$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} rt \cos(n\theta) \\ rt \sin(n\theta) \end{bmatrix}$ <p>r - Radius of circumscribed circle n - Number of turns in spiral θ - Varies from 0 to 2π for complete turn t - 0 1</p>	
Logarithmic Spiral Motif	$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} r_i e^{bt} \cos(n\theta) \\ r_i e^{bt} \sin(n\theta) \end{bmatrix}$ <p>r_i - Minimum radius of Spiral r_o - Radius of circumscribed circle θ - Varies from 0 to 2π for complete turn $b = \log\left(\frac{r_o}{a}\right)$, t - $0, 1$</p>	
Heart shaped Motif	$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} \frac{16r \sin^3(2\pi t)}{13 \cos(\pi) - 5 \cos(2\pi) - 2 \cos(3\pi) - \cos(4\pi)} \\ \frac{r(13 \cos(2\pi t) - 5 \cos(4\pi t) - 2 \cos(6\pi t) - \cos(8\pi t))}{13 \cos(\pi) - 5 \cos(2\pi) - 2 \cos(3\pi) - \cos(4\pi)} \end{bmatrix}$ <p>r - Radius of circumscribed circle to heart shaped geometry t - $0, 1$</p>	

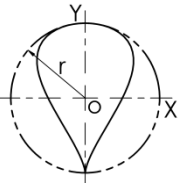
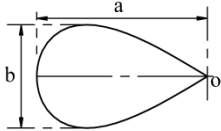
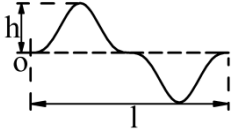
<p>Pear Shaped Motif</p>	$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} a \cos(t) \\ b \sin(t) \sin^c(t/2) \end{bmatrix}$ <p> <i>a</i> - Width of pear geometry <i>b</i> - Height of pear <i>c</i> - the curvature of curve between 0 to 7 <i>t</i> - 0, 2π </p>	
<p>Petal Motif</p>	$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} a \sin(2t) \\ b \sin(4t) \end{bmatrix}$ <p> <i>a</i> - length of petal <i>b</i> - width of petal <i>t</i> - 0, π </p>	
<p>Cubic Sine Motif</p>	$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} lt \\ h \sin^3(t\theta) \end{bmatrix}$ <p> <i>l</i> - length of curve <i>h</i> - height of curve <i>θ</i> - 2π for one cyclic turn and further increases as per cycles required <i>t</i> - 0, 1 </p>	

Table 1: Parametric Definition of Jewelry Motifs.

Private Function createArchSpiral(ByVal planeS As String, ByVal radius As Double, ByVal turns As Double, _
 ByVal centerX As Double, ByVal centerY As Double) As String

Dim calX, calY As String

calX = radius & "*"*(cos(t*" & turns * 2 * pi & "))*"

calY = radius & "*"*(sin(t*" & turns * 2 * pi & "))*"

boolstatus = Part.Extension.SelectByID2(planeS, "PLANE", 0, 0, 0, False, 0, Nothing, 0)

Part.SketchManager.InsertSketch True

Dim equationDriveCurve As Object

Set equationDriveCurve = Part.SketchManager.CreateEquationSpline2(calX, calY, "", 0, 1, False, centerX, _
 centerY, 0, True, True)

Part.SketchManager.InsertSketch True

Set lastFeature1 = Part.FeatureByPositionReverse(0)

createArchSpiral = lastFeature1.Name

End Function

6 CONCEPTUALIZATION OF TWISTED WIRE MOTIF

Traditionally in Filigree jewelry, motifs are generated in the following sequence: Firstly, twisted wire strand is created by twisting two or three plain wires together (Fig.5 (a)) using the rotating wheel machine called "Charkha." Further, twisted wire strand is crimped into a motif shape, filled in a frame (usually made of single wire and with a theme like leaves, rosettes, flowers, animals, especially butterflies and birds) and then soldered expertly (Fig.5 (c)).



Figure 5: Conventional Method of (a) Making twisted wire strand (b) bending wire into motif shape (c) placing motif in a frame and soldering.

In this CAD paradigm, modeling algorithm follows the sequence of sweeping the circular profiles of wires along the predefined motif geometry (circle, star, pear, teardrops, leafs, oval, freeform shapes, etc.) and then twisting the swept profiles along the same trajectory. The circular profiles of wires of radius R_w (up to 4) are sketched on a plane which is normal to geometry of motif, in such a way that each circle touches with its adjacent one (Table 2). Such an arrangement of profiles will result in a twisted wire strand as it braided very tightly when swept and twisted along a motif's geometry.

No. of Wires in Motif shape	Position of circle profile w.r.t Origin	Geometry of Sweep Profile
Frame/Single Wire	0, 0	
Double Wire	$R_w, 0$	
	$-R_w, 0$	
Three Wire	$R_w, R_w/\sqrt{3}$	
	$0, 0.2 * R_w/\sqrt{3}$	
	$-R_w, -R_w/\sqrt{3}$	
Four Wire	R_w, R_w	
	$-R_w, R_w$	
	$-R_w, -R_w$	
	$R_w, -R_w$	

Table 2: Sweep Profiles for creating filigree frame/motifs.



Figure 6: Figure 6: Modeling of twisted wire strand (a) plane for wire profile and sketching geometry (b) sweeping and twisting of wire profile (twisted wire strand made of 3 wires).

7 MODELING PARAMETERS OF JEWELRY MOTIF

It is effortless to modify the filigree jewelry characteristics such as the number of wires, wire size, etc., by parameterization of jewelry motifs. Motif shape parameters limit the length, width, curvature, radius of control polygon/circle, etc. of motif geometry and modeling parameters alter the wire size, number of wires in motif, and twist control in a jewelry motif. The modeling parameters that not only define the motif's outline and but also characterize the twisted wire strand for motifs are as follows:

- Number of wires (N: 1 to 4) in strand
- Size of wire (Rw) defined as radius of wires used in the strand.
- Numbers of turns in strand (n) measure of degree of closeness between wires.

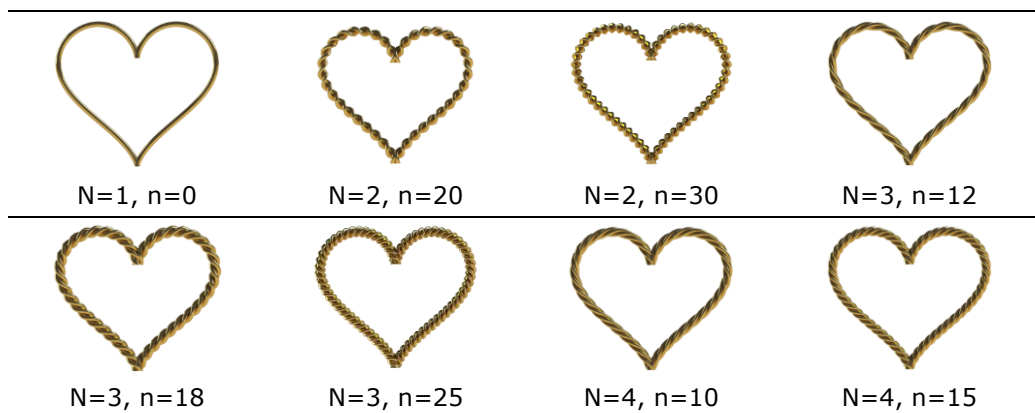


Table 3: Variation in Jewelry motif with change in modeling parameters $r=6$, $Rw=0.25$.

8 MODELLING STEP TO PRODUCE JEWELRY MOTIF/PATTERN

The user participation in design starts by picking a jewelry motif from the library of motif/compound-motif and defining the corresponding attributes' parameter values. The user provides the values of shape/size parameters and modeling parameter. To retain the geometric beauty, constraints are imposed during modeling process at an early sketching level as well in features. Compound-motif is analyzed as a combination of primary motif elements and designed with a unique theme of aligning motifs along a specified trajectory.

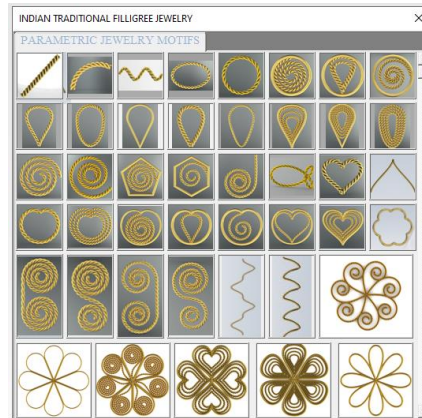


Figure 7: User Interface for Filigree Jewelry.

The CAD API programming algorithm includes the series of modeling steps employed to generate the desired motif's shape by accessing the modeling parameters information through a user interface. Using SolidWorks application programming interface, a user follows the steps listed below for the modeling of motifs as:

1. Start the SolidWorks Part modeling.
2. Run Filigree Jewelry user interface.
3. Select the motif shape from the Jewelry shape database.
4. Input the parameters as required for the jewelry motif.
5. The modeling procedure starts automatically according to input parameters and modeling steps programmed to create the motif designs. The complete modeling procedure and information flow in the paradigm is shown in figure 8.

9 RESULT AND DISCUSSION

The CAD packages provide the feature-based operation (e.g., fillet, hole, sweep, twist) and low-level entities for modeling but the scripting/programming method generates the desired shape by doing a lot of intermediate operation procedurally, saving modeling time. In this paradigm, the designer interacts with the CAD interface at the conceptual level via a declarative modeling approach using knowledge-based information of traditional jewelry to generate the motifs designs. Designers have to enter the low-level and high-level parameters of expected shape and macro-script call the functions and features of CAD through API to create the desired motifs. In this modeling approach, the designer has no need to manipulate the low-level geometric entities to generate shape as all the manipulation and transformation required are defined in the shape parameterization. The jewelry designs are complex in nature, and the designer has to make a concept in mind to break the designs into basic motif shapes. This paradigm generates basic motifs required for complex jewelry design, not final jewelry.

The application developed by customizing CAD tool is sufficient for generating some of the jewelry elements; however, some working knowledge in CAD systems is also required to use this CAD modelers. This jewelry modeler is having the feasibility of creating many jewelry patterns innovatively, inheriting the traditional jewelry style. The pattern is an assembly of several motifs/compound-motifs placed, generally in radial/linear symmetry. The filigree jewelry designs are symmetric about an axis or a plane. Symmetry deals with transformations such as translation, rotation, reflection, etc., that define positions of shapes concerning a two-dimensional plane. The patterns are made by the repetitive use of various elements or shapes at a regular interval at different positions (Fig.9). The modeling constraint at this level is that a whole number of the

motifs/compound-motifs is used, and all the motifs/compound-motifs must have contact with its adjacent one.

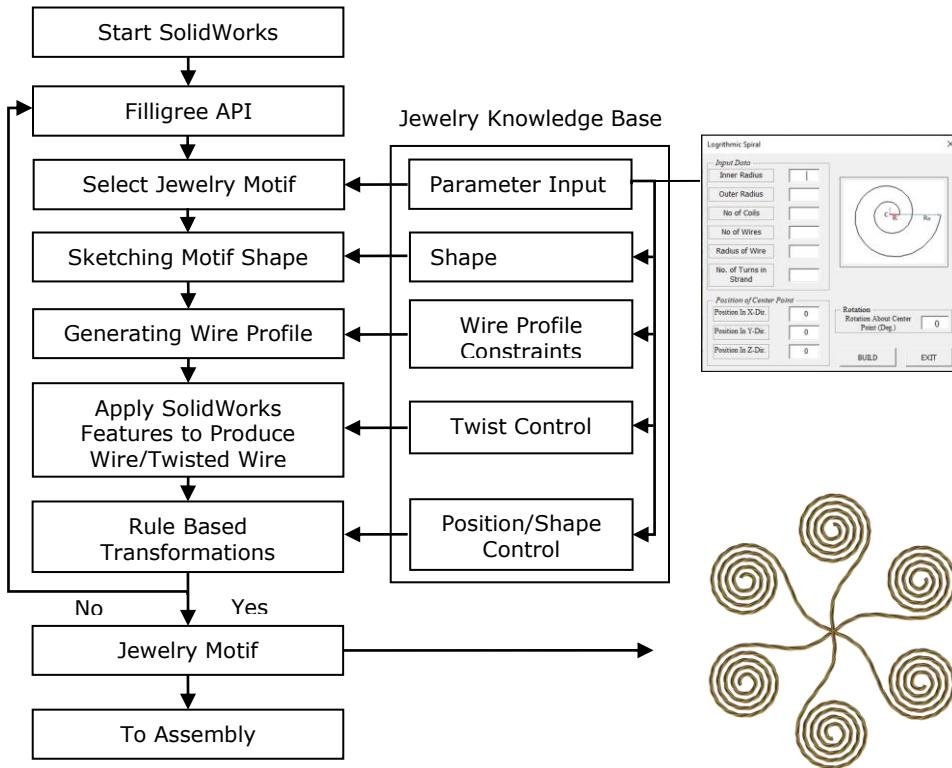


Figure 8: Workflow to Produce Jewelry Motifs.

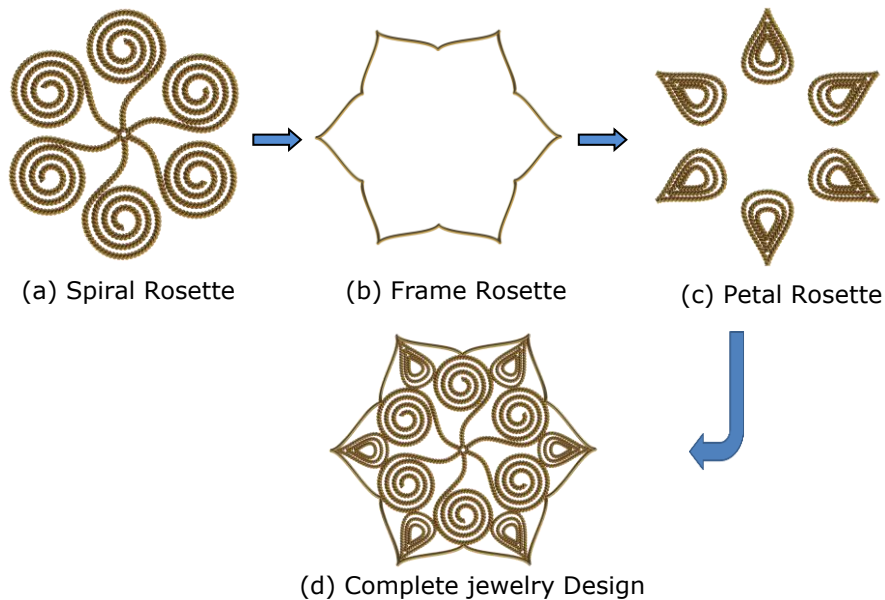


Figure 9: Filigree Jewelry Design Generated using CAD API with three motifs.

The CAD technologies simplify the jewelry designs, whereas modern manufacturing techniques make a real revolution in jewelry manufacturing. Rapid Prototyping is the transformation of digital models to real physical/prototype objects using layer manufacturing techniques whereas in cutting-edge, the tool follows a programmed path. Using these digital technologies designers can produce the master and prototype models directly. Generally, the CAD models are transferred to rapid Prototyping in STL file format, and almost all design software are capable of generating STL files of models. Using the developed CAD paradigm, the designer can design jewelry in a semi-automatic way and produce a master model using 3D printing for traditional manufacturing. With the help of modern CAD/CAM/RP technologies, the designers can refine and improve their creativity and design rapidly compared to traditional techniques.

10 CONCLUDING REMARKS

The integration of handicraft and CAD applies inherited knowledge from ancestors to modern art and crafts to generate new ideas with community culture as the knowledge base and designs show the community's identity. This CAD paradigm provides the capability of creating a wide range of filigree jewelry using the knowledge-based parametric modeling concept. The mathematical approach enables the designers to explore possibilities of novelty in designs by using parametric curves. A knowledge-based system applies design knowledge, design rules, governing rules, and experiential knowledge for product development. Generating geometric shapes by using parametric mathematical equations enables the designers to explore possibilities of creating a wide range of shapes. This jewelry generation method will provide a vast library of interesting shapes that can enhance this jewelry design class. Using this tool, it is also possible to make many more motifs and contemporary design styles with a lot of variation. This parametric jewelry modeling concept is implemented to eliminate the formal jewelry modeling approach by providing the maker's hand with the jewelry modeler.

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