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A Parametric Voxel Based Unified Modeler for Creating Carved Jewelry

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ABSTRACT

This paper presents a parametric voxel based jewelry modeler for designing and creating carved jewelry of sophisticated craftsmanship which is the jewelry with small internal cavities engraved with a thin sharp tool. The modeler is an interactive CAD system, which creates jewelry models that can be prototyped. Computer-Aided Design (CAD) in conjunction with Rapid Prototype (RP) machine produces complex carved jewelry patterns. During the design process a parametric voxel is created. Multiple copies of this parametric voxel are configured into a type of jewelry and joined together to model a jewelry design. Voxel is an integral part of modeling and defined by modeling parameters. A variety of voxel elements can be modeled with appropriate definitions. The variations in designs of jewelry depend upon the richness of voxels in voxel library.

Keywords: parametric, voxel, jewelry, Computer-Aided Design, Rapid Prototyping.
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1. INTRODUCTION

Jewelry is an important object that people wear for their embellishment and CAD and RP technologies are increasingly used in personnel embellishment especially jewelry. These technologies offer a significant break through in jewelry development and demonstrate how creativity and imagination can be perfectly harmonized [4]. By capitalizing the advantages of CAD and RP, especially when it comes to more complex jewelry design generation, this paradigm explains how a pre conceived design intention could be implemented. Both technologies allow the designers to simplify the iterative design, to facilitate modeling of jewelry and to shorten the time required to make the prototype. CAD in conjunction with RP machine can produce complex carved jewelry patterns [6], [19].

The jewelry design involves mainly two aspects such as creativity and development in order to balance the beauty and functions of the products. Creativity of design typically depends on knowledge experiences and perceptions of designs. Jewelry development mainly involves conceptual design process.

The designer employs CAD tool to facilitate the conceptual design process. During conceptual design process, designer generates ideas and CAD is used to represent the ideas into design models. Design factors used in the conceptual jewelry design process are jewelry class, style, size, type and making process. CAD implementation eliminates formal designer and provides the design tool in the hand of user by generating designs of his /her choice. It assists the designer in generating complex jewelry designs, rendering realistically from various viewpoints and converting these jewelry models to STL file format for RP machine.

The RP technology is capable of creating jewelry with small internal cavities and complex geometries. The error free STL neutral file format is sent to workstation software of the RP machine which slices the design model into thin layers. RP process lays the cross sections layer by layer and combines the layers. This process generates real, tangible objects and fabricates complex sacrificial investment casting wax patterns of the jewelry to support customized jewelry.

Designing of complex carved jewelry is a tedious and time-consuming task. It is the class of jewelry having small internal cavities as engraved with a thin sharp tool on the surface of sheet metal. This class of jewelry contains repeated

patterns and can be designed using voxel based technique. In the approach, parametric voxel elements are combined in a wide variety of possibilities to deliver more number of jewelry designs with higher number of variations.
The aim of this paper is to present a parametric voxel based jewelry modeler for designing and creating carved jewelry of sophisticated craftsmanship. The modeler is automated and easy to use. The parameter values are defined by the end user and the creation of the model is carried out by the modeler, based on the specified parameter values. The advantage of such a modeler is that the end user need not have designing skills or knowledge of using CAD systems. Section 2 of the manuscript describes the parametric voxel based approach, while the modeling and manufacturing processes of jewelry are discussed in section 3. Section 4 presents the methodology of creation of voxel elements. The creation process of carved jewelry is elaborated in section 5. Section 6 discussed implementation of the methodology and finally concluding remarks are presented in section 7.

2. THE PARAMETRIC VOXEL BASED APPROACH

The parametric jewelry modeler is developed to capture the designer's intent and to support the concept of variation in designs. A jewelry design is expressed by a set of parameters and constraints. The modeler generates new designs of the jewelry designs by changing the parameters of the modeler. The user participates in the designing process through the definition of these parameters values. The parameters include geometrical, dimensional and location attributes.
The user starts the modeling process by selecting and defining the key parameters of a voxel element. Voxels are predefined structural elements grouped in the voxel library that is an open-ended catalogue to which new voxel elements can be added. The possible variations in designs of jewelry depend upon the richness of voxel elements in voxel library. Voxel is an integral part of modeling and is defined by a set of parametric attributes. A variety of voxel elements can be modeled with appropriate definitions and one such star-shaped voxel element is shown in Fig. 1. During the design process a parametric voxel is created, its multiple copies are configured into a type of jewelry and these configured multiple copies are joined together to model a jewelry design.

Fig. 1: A star-shaped parametric voxel element.

2.1 Objective

The jewelry designs are conceptual and decorative designs that can be parameterized to support customized jewelry design process. The jewelry that confirms to certain repeated patterns can be designed and fabricated using voxel based technique. In the present approach, parametric voxel elements may be combined into a jewelry model in a wide variety of possibilities. The motivation towards adopting this approach falls in the following categories:
1. Evolving solid modeling: The user interactions can be directly turned into 3D solid jewelry models with the change of the parameters.
2. Getting variation in designs: The pressure on today's designer to deliver more number of jewelry deigns with even higher numbers of variations can be released.
3. Improving manufacturability and repeatability: The jewelry making has traditionally been regarded heavily craft based. The user can create a jewelry model of his/her choice and need not have jewelry designing skills. Moreover, he/she can create a design model and produce prototypes repeatedly and accurately.
4. Enabling design and manufacturing integration: Integration of the design and manufacturing can rapidly customize user's requirements by reducing the gap, which traditionally exists between design and manufacturing.

2.2 Structure of the Modeler

The modeler presented in the manuscript has the following capabilities and a modeler of having such type of capabilities is often called a Unified Modeler.
1. It produces a computer understandable model supporting diverse integrated manufacturing.

2. It has a wide modeling range meaning that it is able to generate a wide range of design models.
3. It is able to represent a product, not just a shape of product.
4. It can be easily interfaced with a variety of application programs.
5. It supports a variety of manufacturing applications such as Computer-Aided Process Planning.
6. It creates design models very easily. It has a voxel library from which voxel element is selected as input and converted into design model.

The user interacts with the modeler by selecting a voxel element from a group of predefined voxels in the voxel library. He interactively describes and creates the voxel with modeling attributes and constraints. He defines the basic parameters that refer mostly to the appearances, size and content of the final design model and then construction of the specified model is carried out. Also, by parameterizing the process of creating this class of jewelry, it is very easy to modify characteristics of the jewelry such as size and the designs represented.

The semantic unit is represented by rules that gather up knowledge of the type of jewelry. These rules are grammatically substitutable [2]. These rules configure multiple copies of selected voxel element into a type and shape of jewelry. These rules represent unary (transformation) rules. Boolean operation (Union) is used to concatenate the selected and configured multiple copies of voxel elements. The concatenated model is represented as jewelry design model. Further, this design model is used for rapid prototyping process, which is already explained in section 3.2. The structure of the jewelry modeler is illustrated in Fig. 2.

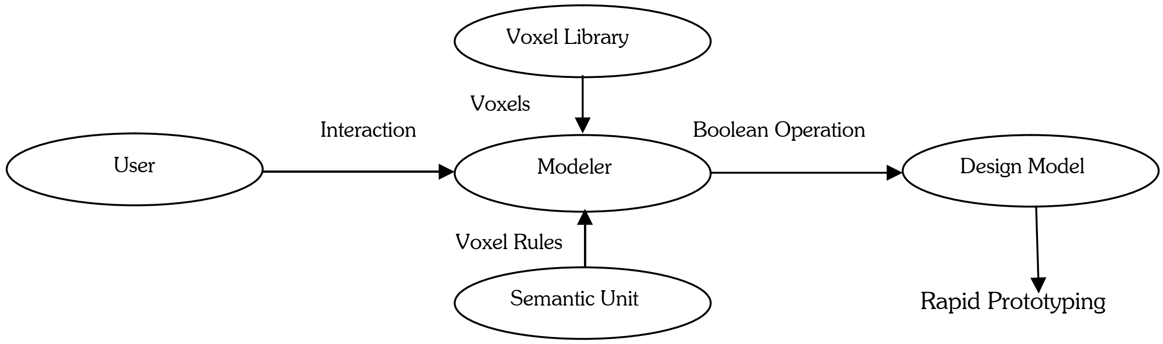


Fig. 2: Structure of the jewelry modeler.

2.3 CAD Systems for Jewelry

The following parametric feature based commercial CAD systems have been developed for the purpose of designing jewelry: (I) Matrix (ii) Rhinoceros (iii) Jewel CAD (iv) Tech Jams (v) Art CAM Jewel Smith (vi) Jewel Space (vii) CAD Jewel 3D. All of these systems provide various tools for making jewelry design models and have very good rendering techniques. All these systems have capability of exporting STL format to RP machines. In most commercial CAD systems for jewelry, designing is performed manually using various tools and usually the design steps cannot be programmed to execute automatically and accurately [1], [10], [11], [18]. ByzantineCAD is a parametric feature based CAD system suitable for the design of pierced medieval Byzantine jewelry. It is an automated system where the design of a piece of jewelry is expressed by a collection of parameters and constraints and the users' participation in the design process is through the definition of the parameters values [15], [16]. Some of interactive feature based approaches to re-engineering jewelry have also been presented. These approaches are aiming to produce robust and accurate models that can either be manufactured or modified to create new jewelry pieces [7], [17] [20].

A parametric voxel based approach has been presented to produce forming components for stretch formed jewelry [8]. In this class of jewelry, the surface of sheet metal is raised by forming tools that are dies and punches having different patterns of designs. This work explains to produce forming components, which are used to emboss the design patterns on thin sheet metal. The embossed surface of sheet metal is reflected by light imposed on it, which helps in visualization of the design to the user. For this class of jewelry, voxels of different shapes are defined in a voxel set based on the aesthetic and artistic knowledge. Different shapes of voxels are placed side by side, either at top, bottom, right or left of each other depending upon the design pattern and concatenate into an alphabet design model. This class of jewelry can be applied to various types of jewelry such as pendants, rings, earrings and bracelets. Rapid prototyping technology is used to fabricate wax patterns of forming tools for stretched formed jewelry.

The proposed approach creates a unique kind of carved pendant and bangle designs as shown in Fig.3, which is not possible to design with the existing commercial systems. For modeling such jewelry, variety of very small structural elements are needed. The presented approach can produce a large number of jewelry designs by changing the modeling parameters. These parameters refer mostly to the appearance, size and content of the final product and help to create the jewelry of specified model.

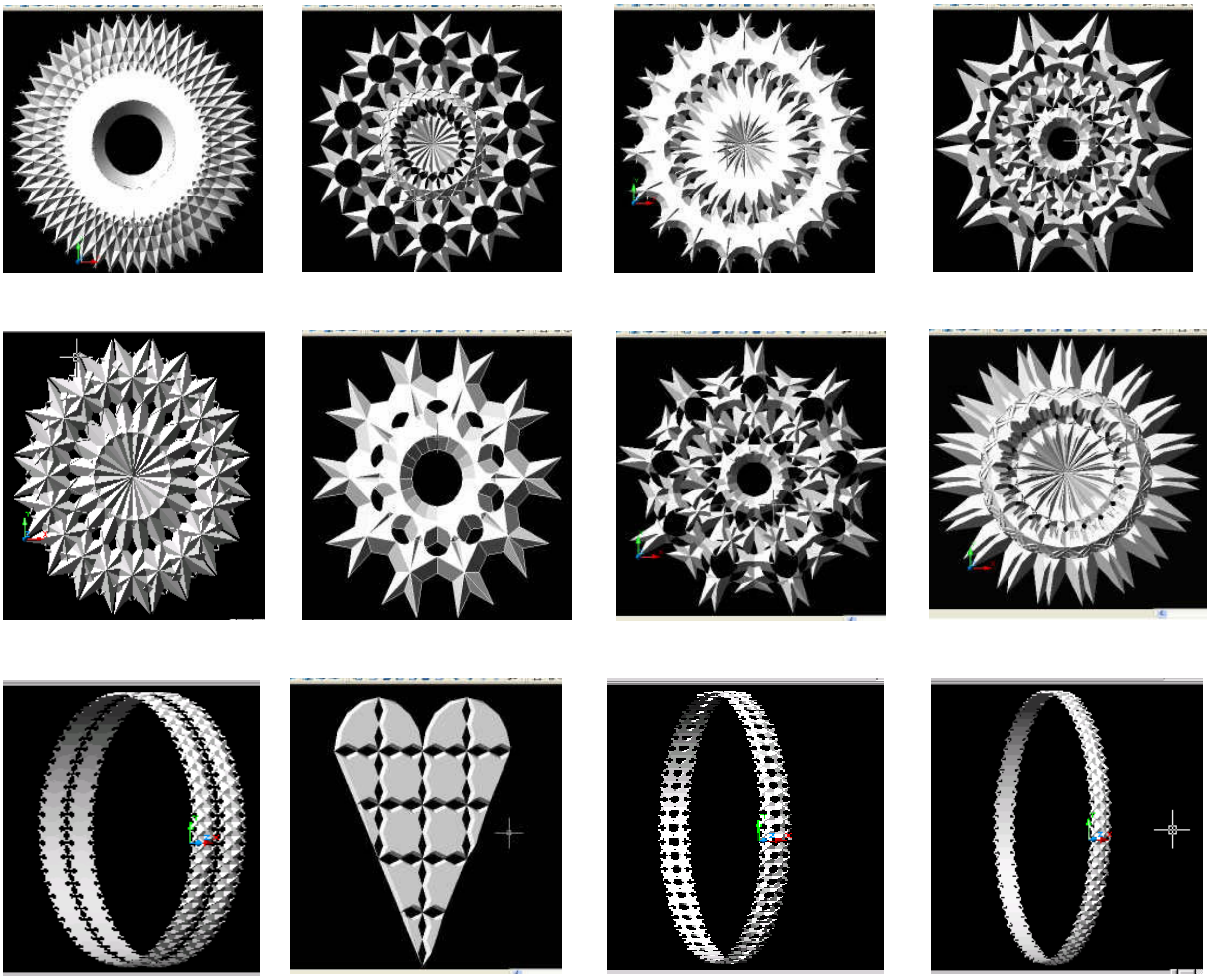


Fig. 3: Samples of design models of pendants and bangles.

3. JEWELRY MODELING AND MANUFACTURING

CAD and RP technologies are offering significant benefits to the jewelry industry. Both technologies are used collaboratively from jewelry designing to manufacturing stage and are capable of producing prototype directly from 3D solid design model. This type of integration of design and manufacturing can shorten the production time [13].

3.1 Jewelry Modeling Process

Jewelry modeling process mainly consists of four steps and its layout is presented in Fig. 4(a) and illustrated as follows:
1. Conceptualization: Jewelry is synthesis of artistic creativity and falls under the category of conceptual and decorative designs. So, conceptualization is an important and creative process in jewelry modeling. It involves two activities: ideation and representation. The ideation means generation of ideas, which is based on intuitiveness, heuristics and human's creativity. Through the process of representations, the ideas are converted to more formal design models. Representation process capitalizes the advantages of CAD system to generate more complex design models.

2. Description and creation of voxel element: Voxels are described and created with geometric attributes and constraints and grouped in voxel library. These voxels are used as structural elements. Each voxel element has features that make it different from other elements.
3. Interpretation of voxel elements for the jewelry type: Voxel elements are interpreted by some rules and configured into a type of jewelry. Rules are unary operations such as transformations.
4. Relationship between voxels: Relationship between configured voxel elements into a jewelry type is referred as voxel attachment operations. These include Boolean operations such as union, subtraction, etc.

3.2 Jewelry Prototyping Process

Jewelry Prototyping process includes five steps, as layout in Fig. 4(b) and illustrated below:
1. Modeling of 3D jewelry design: 3D design model of jewelry is created by the modeler.
2. Creation of STL format: The jewelry modeler is capable of producing STL file. The 3D jewelry model is converted to Standard Triangulation Language (STL), which is the RP defacto standard data transmission format.
3. Validation and repair of STL file: This step is referred as preprocessing. The STL file format approximates the design model using tiny triangles. The STL file is verified to be error free. The STL file is validated and repaired before being sent to RP machine.
4. Slicing of design model: The STL file is transferred to RP machine which slices the design model into thin layers to generate the contours of the models for each layer [3].
5. Prototype building: RP machine lays the sliced sections layer by layer and combines the layers to build wax prototype. These wax patterns are used to create custom jewelry by lost wax process (Investment casting).

3.3 Jewelry Making Process

Rapid prototyping machine produces wax pattern of jewelry. After cleaning the wax, pattern is invested into liquid ceramic slurry, and then into extremely fine sand to form a shell. After the shell has dried, the wax is melted out in a high-pressure steam autoclave, leaving a hollow cavity in the mold that exactly matches the shape of wax model. Before pouring the casting, the shell is fired in an oven burning out any remaining wax or residue and preparing the mold for the molten metal. Pouring can be done using the conventional gravity method. After the casting has cooled, the ceramic shell is broken off and parts are ready to act [14].

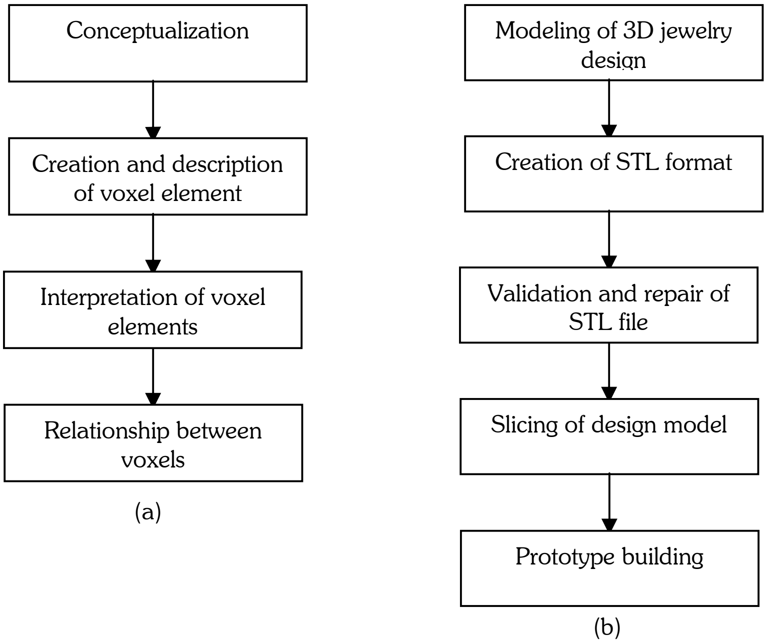


Fig. 4: Jewelry modeling process (a), jewelry prototyping process (b).

4. MODELING OF VOXEL ELEMENT

It is a procedural mechanism in which modeling parameters are addressed to reflect the semantics and the geometric characteristics of the component.

4.1 Modeling Strategy

Voxels are created using the Sketching approach which uses 2D entities to sketch a profile or a cross section followed by 3D operations such as extrusion. Some of profiles and voxel elements created from these profiles are shown in Fig. 5 [9].

1. Select a sketch plane: A sketch plane is needed to create profile. The sketch plane controls the orientation of sketched profile in the 3D modeling space. One of the three perpendicular reference planes (XY, YZ and ZX) of the world coordinate system (WCS) may be selected. The profile is created in the XY plane of the WCS by default.
2. Sketch 2D profile: A profile is generated using comprehensive 2D entities like line and arc. The profile is inscribed in a square and created using a set of valid points as shown in Fig. 6(a). The profile is converted into a region and is described using parameters.
3. Extrude 2D profile: The 2D profile/region is extruded to a sufficient depth and taper angle in a Z direction. The extrusion is perpendicular to the sketch plane of the profile.

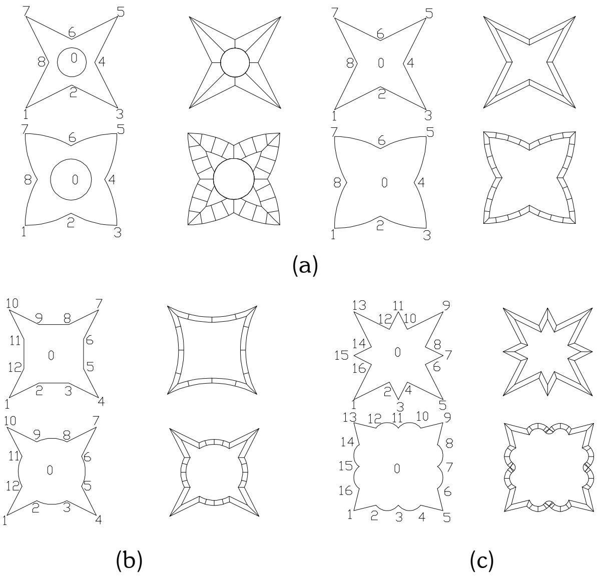


Fig. 5: Voxel elements having nine valid points (a), thirteen valid points (b), seventeen valid points (c).

4.2 Modeling Parameters to Create Voxel

The modeling coverage of jewelry designs depend upon the richness of voxel elements and a variety of voxels elements can be modeled with the appropriate definitions of modeling parameters. The geometry, size and carving aspects can be understood as a collection of parameters. A voxel element is described with voxel signature which is a set of modeling parameters and represented as V-P/L/H/θ/X/Y/R, where V stands for voxel, P for maximum number of valid points, L for size, H for height and θ for inclination of side surface of voxel element, X and Y for variants and R for radius of center hole. All of these modeling parameters are illustrated in Fig. 6 [8].

1. No of valid points (P): The maximum numbers of valid points from which these voxels are created may be nine, thirteen, or seventeen. The profile of voxel element is inscribed in a square. The one center and four corner valid points of the square in which voxel element is inscribed are kept fixed. The rest of the valid points are kept variable.
2. Size of voxel (L): It is the size of the voxel element to be created and kept equal to the size of square. The size of voxel is taken proportionate to the size of jewelry type.
3. Height of voxel (H): It is the height of extruded voxel and equal to depth of extrusion process parallel to Z-axis. This parameter is responsible for the thickness of jewelry, so it needs to be carefully worked out.

4. Inclination of side surface (θ): This represents taper angle of extrusion process along Z-axis. This parameter is responsible for giving carving effect to the jewelry type.
5. Variant (X & Y): These are defined as distances between fixed point and next/previous variable point in horizontal and vertical direction. Variants are used to get different profiles of a voxel class.
6. Radius of center hole (R): Voxel elements may be classified as with or without hole at the center. Center hole is defined by radius.

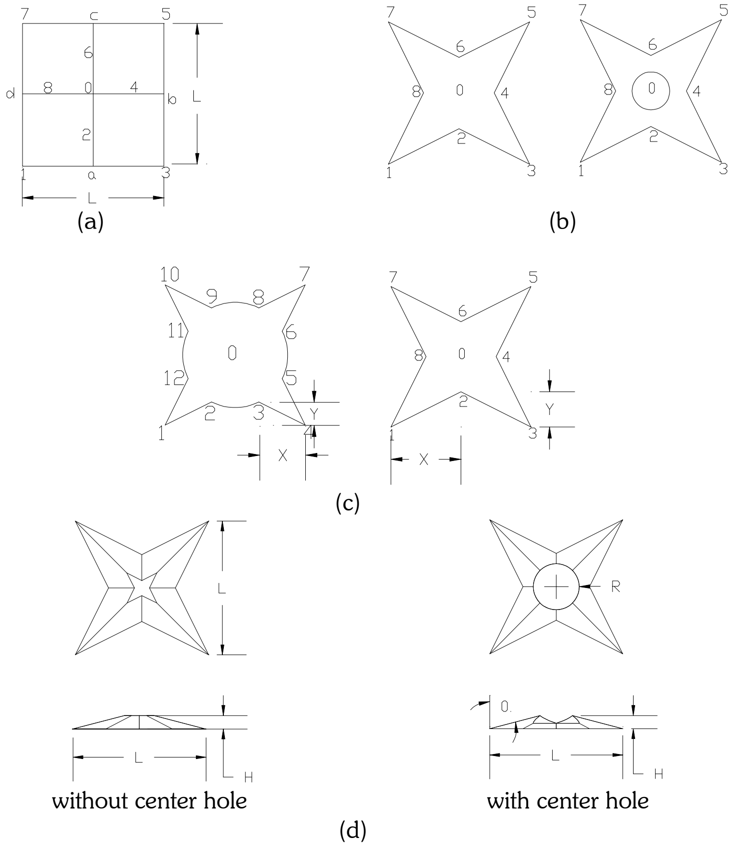


Fig. 6: The square in which profile is inscribed (a), 2D profile with valid points (b), voxel element showing variants (c), extruded voxel element (d).

4.3 An Example: Creation of a Voxel Element

A voxel element of signature V-9/10/1/60/2.5/2.5/2.5 is shown in Fig.6d and illustrated as follows. This voxel element has nine numbers of valid points i.e. from 0 to 8. Points 2, 4, 6, 8 are variable points and points 0, 1, 3, 5, 7 are fixed points. For a voxel of this type, the Coordinates of valid points are: Point 0 = (L/2, L/2), point 1 = (0, 0), point 2 = (X, Y), point 3 = (L, 0), point 4 = (L-Y, X), point 5 = (L, L), point 6 = (X, L-Y), point 7 = (0, L), point 8 = (Y, X). Variable points 2, 4, 6, 8 can vary between points 0 to a, 0 to b, 0 to c, and 0 to d respectively, where coordinates of point a = (L/2, 0), point b = (L, L/2), point c = (L/2, L) and point d = (0, L/2). Distances 2-a, 4-b, 6-c and 8-d are equal and described as variant Y. Distances 1-2, 2-3, 3-4, 4-5, 5-6, 6-7, 7-8, 8-1 are equal and described as variant X. The value of parameters X and Y in the example is 2.5 units. Hole may be created at center taking radius 'R' and center as point 0.

From aesthetic and artistic knowledge, the relations $L/8 \leq X$, $Y \leq 3L/8$ and $R < L/2 - Y$ should be used as constraints for this class of voxels. Size of voxel element is the distance between points 1-3, 3-5, 5-7, and 7-1 which is equal to size of the square in which this voxel is inscribed shown in Fig.6a. For this example, voxel, size is taken as 10 units. The profile 1-2-3-4-5-6-7-8-1 is created using line entities by joining valid points. The profile is extruded with parameters depth of extrusion and taper angle which are kept equal to height of voxel element (in the example as 1 unit) and inclination of side surface (in the example as 60 degrees) respectively. The value of the 'υ' may be taken between 20 to

60 degrees and needs to be carefully worked out. If the taper angle is too large, the profile terminates to a point before it reaches the specified depth. If too small, side surface of voxel will not give much carving effects.

5. THE CREATION OF CARVED JEWELRY

For creating the carved jewelry, a voxel signature is selected for modeling the voxel element. Then, its multiple copies are partially overlapped about an axis of rotation and are unioned with one other [5]. The direction and location of the axis of rotation decides the type of jewelry and size of jewelry respectively. Appearance of jewelry depends on the number of voxels to be overlapped about the axis of rotation.

Each jewelry design as shown in Fig. 3 has same type of internal cavities. This idea to capture the symmetry in carved design minimizes the verbosity of the geometrical definitions. A number of same voxel elements are concatenated to produce symmetrical carved designs. This jewelry modeler is capable of designing pendants and bangles. The process of producing pendant and bangle models is illustrated as follows.

5.1 The Creation of Pendants

The user defines the modeling parameters and then construction of the model is carried out. The process includes of generation of a 2D profile in the XY plane and extrusion along Z-axis to create a voxel element (nine points) as shown in Fig. 7(a). For pendants, the generated voxel is kept in XY plane (front view) as shown in Fig. 7(b). A polar array of this voxel element is created in the same plane. The axis of rotation of polar array is along Z-axis and passing through the center point of array. Center point of array lies in XY plane and takes any one of the valid points so that all voxel elements overlap each other. The center point and the number of voxels in the array decide the appearance and size of pendant. By changing the center point of the array, keeping number of voxel elements in array constant, different designs are obtained as illustrated in Fig. 8a. Also, by changing number of elements keeping same center point of the array, different designs can be obtained as shown in Fig.8b.

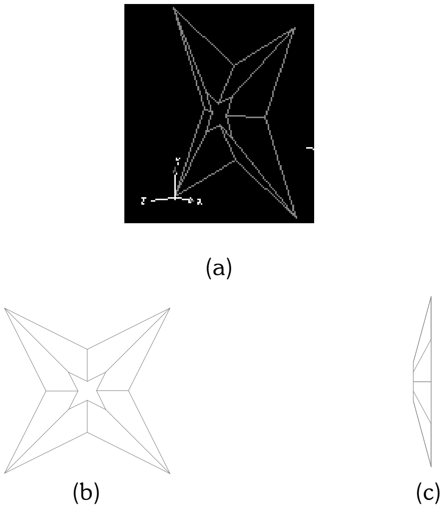
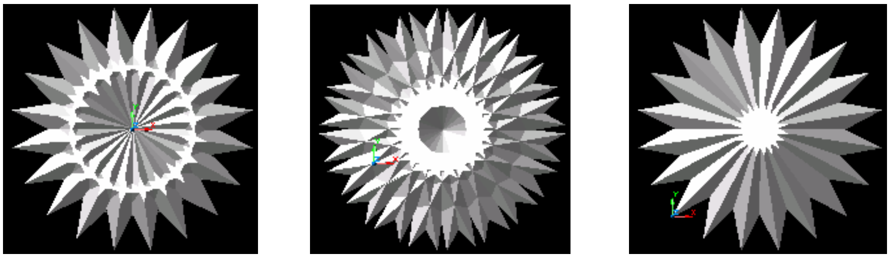


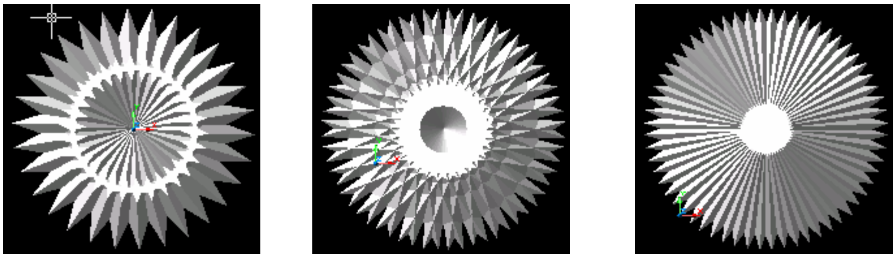
Fig. 7: Generated voxel element (a), voxel in XY plane, front view (b), voxel in YZ plane, side view (c).

5.2 The Creation of Bangles

For creation of bangles, the generated voxel is transformed along its side (say in YZ plane-side view) as shown in Fig. 7(c). For that, a polar array of this element is created in the same plane. The axis of rotation is along X axis passing through center point of array. Center point of array is chosen according to the size of bangle. Horizontal coordinate of center point is kept equal to radius of bangle and vertical coordinate equal to vertical coordinate of valid point 0 (i.e. L/2). As one coordinate of center point is fixed so, by changing the center point keeping number of voxels constant, designs do not change at all. But, by varying the number of elements, design models change. Some of such types of design models are shown in Fig. 9(a) and Fig. 9(b).

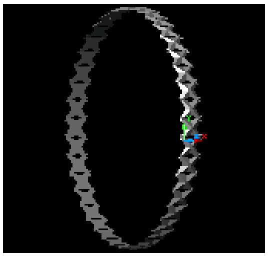


(a)

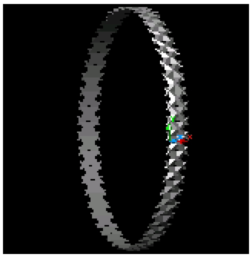


(b)

Fig. 8: Pendants design models having number of voxel elements as 20 and center point as valid points 1, 2 and 3 respectively (a), number of voxel elements as 30 and center point as valid points 1, 2 and 3 respectively (b).



(a)



(b)

Fig. 9: Bangles design models having number of voxel elements as 40 (a), number of voxel elements as 50 (b).

6. IMPLEMENTATION

The paradigm is implemented under the Active X and Visual Basic Application (VBA) programming environment using AutoCAD 04. Microsoft VBA is an object-oriented programming environment designed to provide rich development capabilities. VBA runs in the same process space as AutoCAD, providing an intelligent and very fast programming AutoCAD environment. VBA sends messages to AutoCAD by the AutoCAD ActiveX Automation interface. AutoCAD VBA permits the VBA environment to run simultaneously with AutoCAD and provides programmable control of AutoCAD through the ActiveX Automation interface. This coupling of AutoCAD, ActiveX Automation, and VBA provides an extremely powerful interface. AutoCAD is capable of creating STL file, which can be submitted to Rapid Prototyping machine, for creating wax model [12]. CAD and RP models of generated designs are shown in Fig. 10.

7. CONCLUSION

The paper proposes a new development in the field of jewelry designing to improve manufacturability and repeatability. The approach creates design models using the parameterized voxels. The usefulness of the approach relies on the use of standard tool by CAD system and parameterization of voxels. Computer aided support enhances a concurrent way of working and capitalizes the advantages of computer over hand, especially when it comes to more complex jewelry designs generation. The basic objective is to eliminate formal designer and provide the design tool in the hand of the user capable of generating a large number of designs.

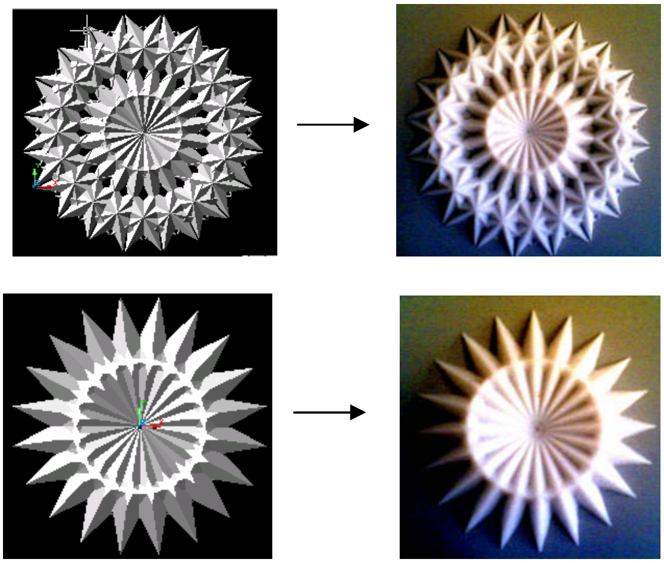


Fig. 10: CAD (left) and its RP (right) models.

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