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Flexible Jewelry Design Based on Fractal Aesthetics: A User-Centered Approach for Iranian Young Women

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Abstract

This research interrogates the systemic "design gap" and industrial stagnation within the Iranian jewelry sector, characterized by a regressive reliance on aesthetic imitation and a neglect of systematic Design Thinking methodologies. By operationalizing a User-Centered Design (UCD) framework, the study aims to develop a multi-functional, convertible ornament tailored to the evolving value perceptions of young Iranian women (16-20 years), who increasingly prioritize design-led innovation and functional versatility over traditional material commodity weight. Adopting a rigorous applied mixed-methods approach, the study synthesizes the structural principles of Fractal Aesthetics Theory (FAT) with Bionic engineering for mechanical articulation. Empirical data were elicited from a purposive sample of vocational arts students (n=44) via the non-verbal PrEmo instrument to mitigate verbal bias in emotional validation, followed by the application of the Analytic Hierarchy Process (AHP) to computationally prioritize design parameters and resolve the "Tripartite Constraint" of aesthetics, functionality, and economic feasibility. Quantitative analysis confirms a significant generational pivot toward minimalist-angular geometries, specifically validating the Koch Fractal's high aesthetic resonance, while establishing a functional protocol for Ring-to-Pendant convertibility. Furthermore, the findings justify a strategic transition to optimized silver-based modularity, as 78% of the target demographic prioritized contemporary design value over traditional gold mass. Ultimately, this study contributes an empirically validated blueprint for industrial revitalization, offering a replicable strategy to elevate the sector from a commodity-centric model to a source of sustainable, innovation-driven competitive advantage.

Keywords

Design Thinking, User-Centered Design (UCD), Flexible Jewelry, Fractal Aesthetics, PrEmo Tool.

Introduction

The Iranian gold and jewelry industry, while boasting a rich and profound historical lineage characterized by sophisticated craftsmanship, currently faces critical systemic challenges (Ehsani, 2003; Mohammadpanah, 2009). marked by market stagnation and a profound "design gap". Historically, the industry's economic resilience has been predicated on the material's inherent value, operating essentially as a commodity-centric model where the gold itself is the primary value proposition, overshadowing design innovation. This traditional reliance has fostered a production environment heavily characterized by passive imitation of foreign aesthetics (Bonyan Afarinan Jelveh Company, 2023) and an ideological resistance to incorporating systematic design philosophies, such as Design Thinking (DT) and User-Centered Design (UCD)[1], an approach that this research posits is economically unsustainable, particularly given contemporary global market dynamics and specific shifts in domestic consumer behavior. (HajiJalili, 2025)

The core problem addressed by this study is the critical disconnect between the industry's traditional, material-value-driven production model and the rapidly evolving, design-and-function-driven needs of the emerging Iranian youth demographic. Specifically, young women (16-20 years) are highly sensitive to both severe economic constraints and contemporary cultural trends, demanding products that offer high perceived value, creative functional flexibility, and distinctive, unique aesthetics at an accessible price point. The industry's failure to meet these conflicting demands results in a Tripartite Constraint: the necessity of simultaneously satisfying three high-priority criteria: high aesthetic quality, robust functionality (convertibility), and cost-effectiveness, a challenge which commodity-centric manufacturing methods are structurally incapable of resolving.

Therefore, the primary research question driving this inquiry is: How can a systematic UCD framework, rigorously informed by the structural aesthetic principles of Fractal Aesthetics Theory (FAT)[2] and applied quantitative methods such as the Analytic Hierarchy Process (AHP), be utilized to successfully develop a flexible jewelry design that resolves the tripartite constraint and strategically shifts the industry's value proposition? This question underscores the need for an empirically supported methodology that can transform subjective consumer desires into quantifiable design targets, ensuring the final product is both desirable and technically feasible.

The primary goal of this study is to design a validated, multi-functional, and aesthetically sophisticated ornament based on empirical user data and fractal aesthetics principles, serving as a tangible, data-driven model for industrial transformation. The study aims to rigorously document the methodology and the empirical process necessary for transforming subjective user desires into a technically feasible, economically logical, and market-ready product, thereby proving that a focus on innovation and quantifiable user value can supersede reliance on material weight. The subsequent sections will detail the theoretical underpinnings, the mixed-methodology utilized, and the empirical resolution of the design problem (Cross, 2008; Heskett, 2005).

This research is explicitly framed as an applied case study rather than the proposal of a novel design methodology.

Notes:

[1] User-Centric Design (UCD): The core methodological approach mandating that design outcomes prioritize measurable user needs, including usability and ergonomic comfort, over subjective artistic biases.

[2] Fractal Aesthetics Theory (FAT): The aesthetic innovation framework rooted in the geometric principles of self-similarity, infinite complexity, and fractional dimension. It is validated by research suggesting a strong human aesthetic preference for forms with a D-value between 1.3 and 1.5.

The study systematically operationalizes established user-centered and decision-support frameworks (UCD, QFD, AHP, and PrEmo) within a specific socio-cultural and economic context to develop and validate a

single convertible jewelry product. The primary contribution of the article lies in demonstrating how these existing frameworks can be integrated and applied coherently to resolve a real-world design constraint, rather than in introducing a new synthetic design method.

Methodology

The design and validation processes for this research were strictly governed by a rigorous applied mixed-methodology approach, aiming to generate concrete, implementable design solutions grounded in empirical data. The overall process was guided by the iterative and adaptive framework of UCD (Norman, 1988), which mandates placing the user's needs and context at the epicenter of the design problem-solving cycle. The methodology strategically combined qualitative techniques for deep user insight with quantitative methods for objective prioritization and validation, ensuring that all design decisions were empirically justified.

1. *Research Approach and Design Goal*

This study is descriptive in nature, with an applied research goal focused on the development of a functional product. The methodological framework is rooted in UCD, operationalized through the iterative process-model defined in the ISO 9241-210 standard (ISO, 2019; Norman, 1988). (Figure 1). This structured approach ensures a systematic transition from understanding user contexts to the final evaluation of designs. By adhering to this internationally recognized cyclical model, the research effectively translates abstract emotional and aesthetic requirements into precise, quantifiable engineering parameters, thereby mitigating the risks of design misalignment with the target demographic.

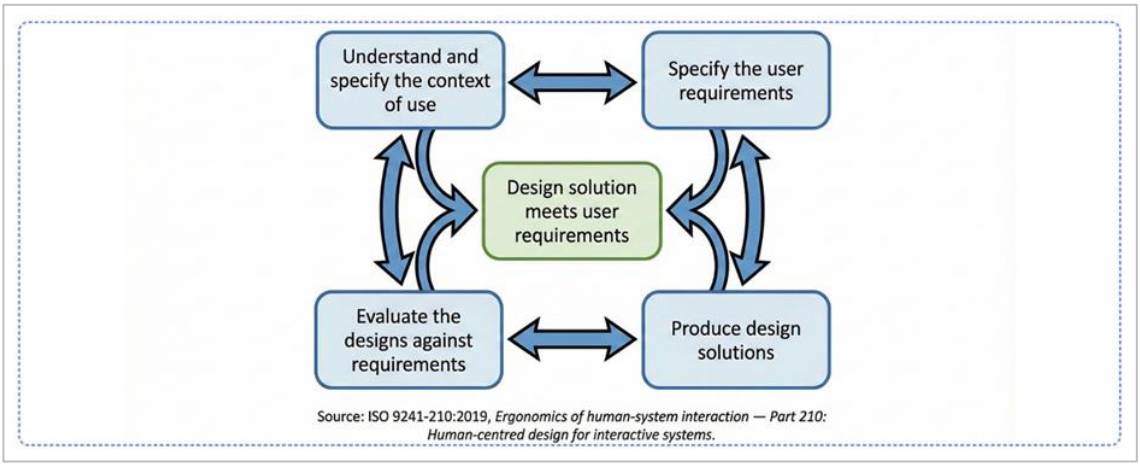

Figure 1: *The Interdependent Method of Human-Centered Design Activities* (Adapted from ISO, 2019)

2. *Population and Sampling*

The statistical population for this study comprised female high school and vocational arts students in the Tehran metropolitan area. A highly selective, non-probability purposive sample of 44 female students, aged 16 to 20 years, was chosen. The sample selection was deliberate, focusing on students specializing in related design fields (Graphic Design, Fashion Design, and Interior Architecture). This targeted sampling ensured that the participants possessed an elevated level of design literacy and represented the most relevant, trend-aware segment of the target consumer demographic for contemporary jewelry (Desmet, 2003). The purposive sampling strategy intentionally focused on design-literate participants. While this approach introduces an inherent selection bias, it was a deliberate methodological decision aligned with the exploratory and design-driven nature of this case study. The selected participants represent a highly trend-aware sub-segment of young Iranian consumers, rather than the full diversity of the national jewelry market.

3. *Data Collection Instruments and Validation*

To bridge the gap between subjective user aspirations and technical execution, a triangulation of sophisticated instruments was employed. The research utilized a comprehensive 18-item questionnaire to establish baseline demographic data and initial material preferences. To mitigate verbal bias and capture nuanced emotional responses to fractal geometries, the PrEmo[2] (Product Emotion Measurement) instrument, a non-verbal self-report tool, was administered. Given that the sample consisted of design-literate students, PrEmo provided a high-fidelity objective measure of aesthetic resonance. The resulting emotional intensity scores, specifically in response to the Koch Snowflake fractal[1] (Figure 2).

The Koch Snowflake was not assumed a priori as the final aesthetic basis of the design. During the early ideation phase, multiple fractal geometries, including Koch-based, Mandelbrot-derived, and Sierpiński-inspired forms, were considered as potential aesthetic structures. These alternatives were systematically evaluated using the PrEmo non-verbal emotion measurement tool. The Koch Snowflake demonstrated significantly higher positive emotional intensity scores compared to other tested fractal forms, leading to its empirical selection as the final design geometry. Moreover, the Koch Snowflake is a canonical example within fractal aesthetics literature and is frequently cited as a standard angular fractal with a fractal dimension within the perceptually preferred range ($D \approx 1.26–1.5$).

Furthermore, the Quality Function Deployment (QFD) methodology was specifically applied to translate the "Voice of the Customer" (VOC) into actionable engineering requirements, ensuring that the qualitative user needs were mapped onto technical design parameters.

Note:

[1] Koch Snowflake Fractal: The specific, angular geometric motif chosen for the final design, validated by research showing a user preference for Angular Geometric Forms (57.14%).

[2] PrEmo (Product Emotion Measurement): A specialized non-verbal instrument utilizing 14 animated cartoon characters to objectively quantify aesthetic impact and capture nuanced emotional responses from participants.

Finally, the Analytic Hierarchy Process (AHP) was operationalized to computationally prioritize these requirements. This ensured a mathematically verified resolution to the "Tripartite Constraint" of aesthetics, functionality, and cost, providing a robust foundation for the subsequent ideation phase.

The validity of the instruments was established through expert consensus among four faculty members in industrial and applied design. Internal reliability was rigorously confirmed using Cronbach's Alpha (*alpha* = 0.78), exceeding the standard threshold for exploratory research.

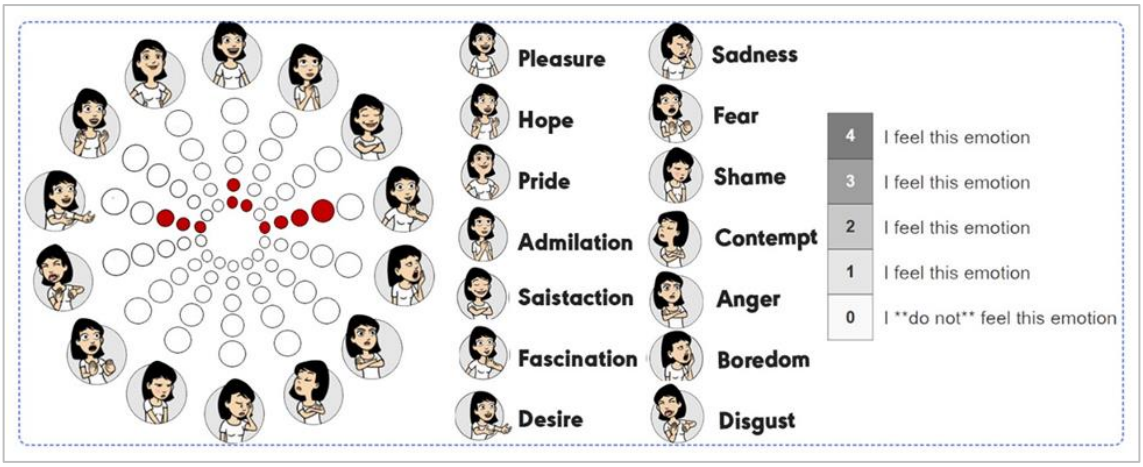

Figure 2: *PrEmo Results, Chart illustrating emotional intensity scores in response to the Koch Snowflake fractal*

4. *Data Analysis Process*

Data analysis was conducted through a dual-track integrated framework designed to ensure both mathematical and thematic precision throughout the research process. In the qualitative track, data elicited from the initial UCD empathy stage, including open-ended questionnaire responses and user interviews, were subjected to rigorous Thematic Analysis to establish core user narratives and define specific functional requirements. Simultaneously, the quantitative track involved processing numerical data from the comprehensive questionnaire and the PrEmo assessment using the Statistical Package for the Social Sciences (SPSS) to generate both descriptive and inferential statistics (Saaty, 2008; Akao, 2004).

To resolve the design constraints, the pairwise comparison matrices of the Analytic Hierarchy Process (AHP) were computationally analyzed using Expert Choice Software. This systematic approach ensured mathematical rigor in calculating the definitive priority vector and confirming a Consistency Ratio ($CR < 0.1$) for all hierarchical judgments, thereby providing a verified foundation for the subsequent design phases.

Theoretical Foundations and Contextual Literature

The following theoretical frameworks are presented selectively to support the analytical structure of the case study. Rather than serving as an exhaustive review of design and management theories, these frameworks are introduced solely insofar as they directly inform the design decisions and empirical outcomes of the presented case.

The methodological and aesthetic structure of this research is predicated upon a synergistic theoretical model that intentionally integrates strategic design philosophy with specialized structural and analytical frameworks, moving beyond a simple historical review.

1. *Core Theoretical Pillars*

- **User-Centered Design (UCD) and Design Thinking**

  User-Centered Design (UCD) serves as the overarching strategic framework for this research, ensuring that the design process remains fundamentally aligned with the user's cognitive and emotional context. Rooted in the iterative philosophy of Design Thinking, UCD prioritizes a deep understanding of the user through empathy and cyclical validation to address genuine usability and functional gaps (Mandelbrot, 1982; Eskandardoust, 2020; Taylor et al., 2011).

  While the UCD framework establishes the human-centric philosophy of the study, it is strategically integrated with Quality Function Deployment (QFD) to provide a rigorous mechanism for technical translation. In this context, UCD ensures that the design solution remains desirable and usable for the target 16–20-year-old female demographic, while QFD operationalizes the "Voice of the Customer" (VOC) into concrete, measurable engineering parameters. This synergy allows the research to move beyond subjective artistic intuition, ensuring that every aesthetic and mechanical feature of the "Snowflakes" ornament is an empirical response to validated user requirements.

- **Fractal Aesthetics Theory (FAT)**

  FAT provided the essential aesthetic and structural language, rooted in the geometric principles of self-similarity and infinite complexity. This theory posits that specific fractal patterns resonate profoundly with human visual perception and emotion due to an innate preference for their balanced complexity, often corresponding to a fractional dimension (D-value between 1.3 and 1.5). By selecting the specific Koch fractal based on quantitative user preference (Figure 2), the design gained an aesthetic basis that is both mathematically precise and universally appealing. Figure 3 illustrates the geometric development of the chosen aesthetic basis.

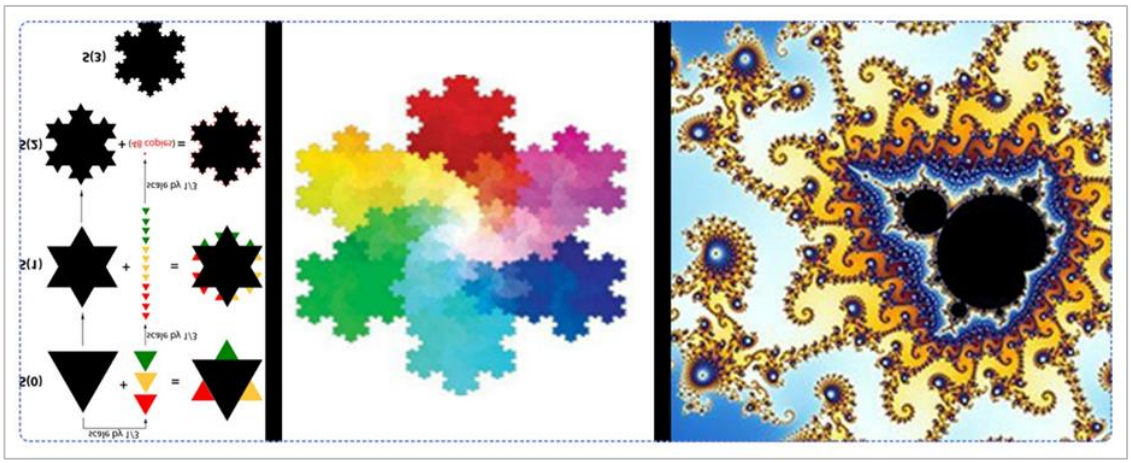

Figure 3: *Fractal study models: Koch curve & Mandelbrot set forms*

- **Bionics and Flexible Mechanism Principles**
  To ensure the technical robustness of the flexible, convertible function, the design leveraged principles derived from Bionics (Biomimicry)[1]. Bionics informed the engineering of the complex, precision-based joints, specifically hinges and pins, required for the seamless Ring-to-Pendant conversion. Specifically, the research analyzed arthropod joint mechanisms (such as those found in insect appendages), which offer an exceptional strength-to-weight ratio and precise rotational freedom. These natural articulations inspired the creation of small, lightweight, yet highly durable mechanisms, which were crucial for meeting the functional mandate without causing structural fatigue (Gérardain, 2018; Peitgen et al., 1992). In the final design, these bionic principles were translated into the modular hinge-and-pin system of the "Snowflakes" ornament. The articulation points between the Flexible Link Section (R2) and the main body mimics a dicondylic joint structure. This bio-inspired engineering ensures that the transition between forms is fluid and repeatable, maintaining the durability required for a high-frequency convertible product while remaining remarkably lightweight to match the user's preference for silver.

Note:
[1] Bionics (Biomimicry): The technical framework used to inform the realization of robust, repeatable flexibility by extracting optimized structural mechanisms from biological systems.

2. *Historical and Contemporary Context of Iranian Jewelry Design*

The Iranian gold and jewelry sector, despite a seven-thousand-year legacy of metalworking artistry, is paralyzed by systemic stagnation, contributing less than one percent to the global gold trade. The literature identifies the primary affliction as an ideological resistance to systematic Design Thinking and UCD principles, resulting in a persistent reliance on copying molds from foreign markets (Italy, Turkey, etc.) (Ehsani, 2003; Ziapour, 1969).

This failure to innovate is compounded by severe macroeconomic instability, which restricts consumer purchasing power and makes traditional gold items unattainable. Concurrently, a fundamental cultural transformation is evident among the emergent generation of young women, who actively prioritize aesthetic and functional value over mere material weight. This market shift mandates an irrevocable pivot from Gold Weight (commodity value) to Design Innovation and Functional Flexibility (experiential value). Figure 4 and Figure 5 contextualize this aesthetic shift by displaying historical and contemporary domestic jewelry motifs.

3. *Review of Modular and Convertible Products*

A competitive review confirms that successful, repeatable convertibility relies universally on complex, precision-engineered mechanical articulation. Iconic international pieces, such as the Van Cleef & Arpels' Zip Necklace (Figure 6) and Chaumet's convertible pieces (Figure 7), demonstrate transformation through intricate zipper mechanisms and robust attachments.

Figure 4: *Historical nature-inspired jewelry motifs across civilizations*

Figure 5: *Contemporary Iranian conceptual jewelry examples* (ariaart.gallery)

Figure 6: *Example of the Van Cleef & Arpels Zip Necklace illustrating necklace-to-bracelet conversion- Coco Chanel headband-Chaumeth Necklace*

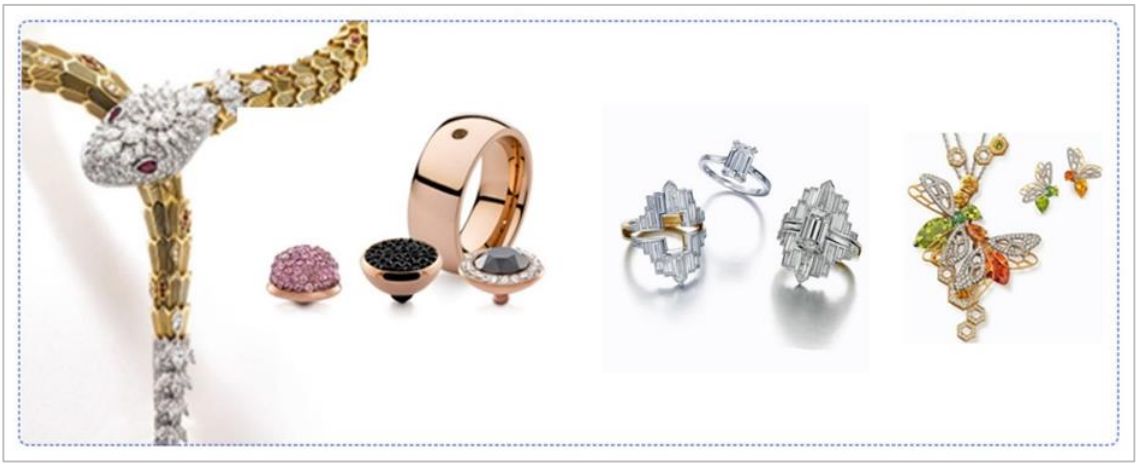

Figure 7: *Example of the Van Cleef & Arpels Zip Necklace illustrating necklace-to-bracelet conversion- Coco Chanel headband-Chaumeth Necklace*

However, these models are inaccessible to the Iranian market due to prohibitive cost and logistical barriers, failing to address the core economic constraint. The domestic market analysis confirmed the complete absence of any registered, mass-produced Iranian multi-purpose jewelry. Furthermore, an analysis of the competitive landscape using a SWOT framework (Table 1) confirmed the critical market void this research addresses: the lack of an affordable, functional, and aesthetically proprietary design for the target youth demographic.

Table 1: *Synthesis of SWOT Analysis and Market Review Findings*

Strengths (S)	Weaknesses (W)	Opportunities (O)	Threats (T)
Design innovation & proprietary aesthetic (fractal).	Lack of domestic design culture (reliance on foreign molds).	Unfilled Iranian youth market seeking UCD/unique designs.	High cost of gold and jewelry vs. low-cost costume jewelry.
Robust mechanical articulation in international models (hinges/pins).	High production costs and Lack of exports	Potential for material substitution Semi-precious metals (silver, etc.) to lower cost.	Market stagnation due to VAT laws and currency devaluation.
High domestic technological capacity for production (Vacuum or induction casting).	Logistical and high-cost barriers for importing unique pieces.	Ability to leverage domestic resources for lower final cost.	Competition from established global luxury brands.

Research Body: Process and Findings

This section details the systematic execution of the UCD mandate, translating qualitative emotional data and quantitative preference scores into non-negotiable design criteria and ultimately a validated product concept.

1. *Initial Data Acquisition and Aesthetic Validation*

The initial phase captured explicit user preferences and the underlying emotional responses to aesthetic stimuli. Analysis of the comprehensive questionnaire revealed a decisive generational rejection of traditional ornate patterns (0% preference) in favor of the Modern/Minimalist style (75% combined preference). This aesthetic mandate was defined by a strong preference for Angular Geometric Forms (57.14%). The PrEmo scores (Figure 2) unequivocally validated the high aesthetic desirability of the Koch Fractal geometry. Functionally, the priority was for Ring-to-Pendant conversion (47.61%), and economically, Silver was the most practical material choice (25.40%). Table 2 summarizes these key user preferences. (Bonyan Afarinan Jelveh Company, 2023).

Table 2: *Summary of Key User Preferences: Material, Form, and Style*

Attribute Category	Most Preferred Choice	Percentage (%)
Jewelry Type	Complete Set/Single Piece	40.90% / 34.09%
Desired Material (Attainable)	Silver	25.40%
Preferred Fractal Form	Angular Geometric (Koch Snowflake)	57.14%
Preferred Metal Finish	white gold plating / silver plating	45.45% / 25.25%
Preferred Stone Color	Cold / Neutral Tones	76.74% / 13.95%

This data was further refined through the development of user personas, which translated the qualitative "Customer Voice" into technical requirements, as documented in the Voice of Customer Table (Table 4).

2. *Design Criteria Quantification and Prioritization (QFD and AHP)*

The qualitative Voice of the Customer (VOC) was formally structured and translated into technical mandates using Quality Function Deployment (QFD). This process established the technical requirement categories and categorized them using the Kano Model (Table 5). Subsequently, the Paired Comparison Method (PCM), integral to the AHP framework, was employed to weight the five design criteria (Aesthetics, Function, Cost, Ergonomics, Semiotics). The resulting priority vector decisively confirmed the overwhelming influence of the Tripartite Constraint (Aesthetics, Performance / Function, and Cost), which collectively commanded over 80% of the total design focus (Table 3).

Table 3: *Design Criterion Priority Hierarchy*

Design Criterion	Calculated Priority Vector (Weight)	Relative Rank	Core Justification
Aesthetics (Beauty)	30.67	1	Must deliver novel, user-preferred fractal forms and style.
Performance Function	26.92	2	Must ensure robust, repeatable convertibility mechanism.
Cost and Production Feasibility	23.07	3	Criticality of affordability through material and weight optimization.
Ergonomics (Comfort Safety)	15.38	4	Ensuring daily, safe wear (no nickel, sharp edges, appropriate weight size).
Semiotics Meaning	3.84	5	Symbolic storytelling (Youthful Vigor, Hope) integrated into the form.

Table 4: *Voice of Customer Table*

Row	Customer Profile	Customer Voice	Use (W5H)				Requirements Review
			What	When	Where	How	
1	Ainaz - Age 17 - 11th Grade Fashion Design - ENFJ	Prefers Ancient Iranian style, seeks fashion and originality, wants a jewelry that reflects her personality, is special, modern, and has a story. Must have separation and rearrangement flexibility. Likes natural fractals, asymmetrical structure, white plating, warm stones, sandblasted texture.Wants a pendant that converts to a ring.]	Pendant to Ring	All times	All places	Jewelry inspired by natural fractals that reflects my personality	Style should be Ancient Iranian.Design should reflect personality and story. Must have separation and rearrangement flexibility.
2	Tara - Age 18 - 12th Grade Jewelry Design - ESFJ	Prefers Modern style, wants to wear jewelry Prefers Modern style, wants to wear jewelry everywhere/all the time. Needs a flexible piece in yellow gold with neutral stones, inspired by the Koch Snowflake fractal, with a symmetrical angled geometric structure. Wants a meaningful, flexible piece with add/subtract capability. Prefers carved texture. Wants a pendant that converts to a ring.	Pendant to Ring	All times	All places	Proportionate and creative design inspired by fractals	Style should be Modern.Color yellow, neutral stones, Koch fractal, angled geometry, symmetrical. Must have add/subtract flexibility.
3	Rosta - Age 18 - 12th Grade Graphic Design - ENFP	Prefers Minimalist style, white gold, cool stones, symmetrical structure. Wants a new, beautiful design w ith the concept of 'hope,' a unique piece that can change shape via connections. Likes Mandelbrot fractal, curved forms, single pieces. Wants a pendant that converts to a bracelet.	Pendant to Bracelet	All times	All places	Design a unique piece just for me	Style should be Minimal. Color white, cool stones, Mandelbrot fractal, curved forms, change shape flexibility.

Table 5: *KANO Model Summary*

Basic Quality (BQ) Requirements	Performance Quality (PQ) Requirements	Excitement Quality (EQ) Requirements
* Desirable safety * Non-repetitive and non-imitative form * Production quality in terms of appearance and function * Regular and strong setting to prevent stone loss * Color stability	* New, creative, and beautiful design, compliant with the aesthetic, ergonomic, and semiotics needs of contemporary young users * Multi-purpose jewelry * Flexibility through connections *User-changeable * Substitution of precious metals with semi-precious metals with the same delicacy and quality * Inspiration from attractive sources (Koch, Mandelbrot, natural fractals) *Substitution of semi-precious stones with desirable cuts and delicate setting * Suitable price	* Jewelry with other utility (perfume dispenser, tool, etc.) *Smart jewelry (GPS, QR code, blood sugar sensor) * Jewelry with gender-flexible, memory-retaining material * Jewelry with a compatible box that protects it from damage and theft, and has GPS to notify the owner of movement

3. *Ideation and Technical Contradiction Resolution (TRIZ)*

The ideation phase filtered preliminary ideas using the Morphological Chart (Figure 8), ensuring the systematic combination of functional parameters (e.g., hinge types) with the angular fractal aesthetic.

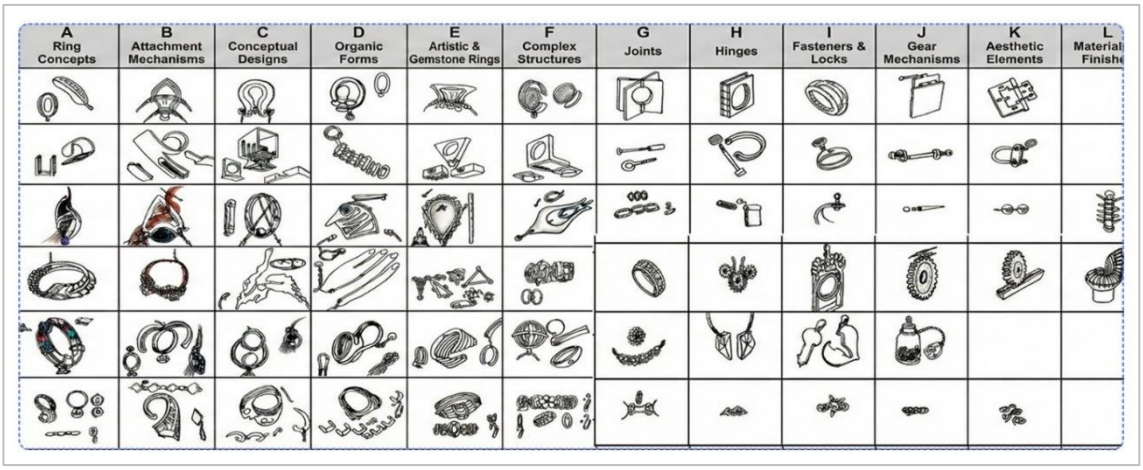

Figure 8: *Illustration of the Morphological Chart used for systematic ideation of mechanical and aesthetic combinations*

The core technical challenge, enhancing Durability/Strength while simultaneously minimizing Weight/Material Use, was resolved using the principles of TRIZ (Theory of Inventive Problem Solving)[1]. TRIZ mandated solutions involving Dynamicity (Principle 15, using precise, multiple articulated joints) and Composite Materials (Principle 40, using durable steel alloy for micro-pins alongside lightweight silver (Van Cleef & Arpels, 2023; Chaumet, 2023).

This resulted in the definitive structural motif: the Koch Snowflake geometry, translated directly into the structure of the R2 Flexible Link Sections for modular articulation. Table 6 summarizes the technical resolution derived from the ideation process.

Table 6: *Illustration of the Morphological Chart used for systematic ideation of mechanical and aesthetic combinations*

Parameter to Improve	Parameter to Reduce (Constraint)	Core Strategic Resolution	Implementation in Design
Durability/Strength	Weight/Material Use	Composite Materials (Principle 40)	Utilize durable steel alloy for micro-pins/connectors alongside lightweight silver
Functional Stability	Simplicity	Dynamicity (Principle 15)	Employ multiple, precisely machined articulated joints for robust function

Note

[1] TRIZ (Theory of Inventive Problem Solving): A methodology used to solve core technical contradictions, specifically mandating solutions like Composite Materials (Principle 40) and Dynamicity (Principle 15) to enhance durability while minimizing material weight.

4. *Final Conceptual Selection and DFX Validation*

The three strongest design candidates (Figure 9) were subjected to the final Analytic Hierarchy Process (AHP) for definitive selection, involving rigorous pairwise comparison against the weighted criteria.

The AHP process involved detailed comparisons against each criterion, including Performance, Beauty, and Cost, confirming Design Concept One's superior reconciliation of all requirements. Design Concept One ("Snowflakes") proved to be the mathematically uncontested superior idea, achieving an overwhelming final priority weight (Table 7).

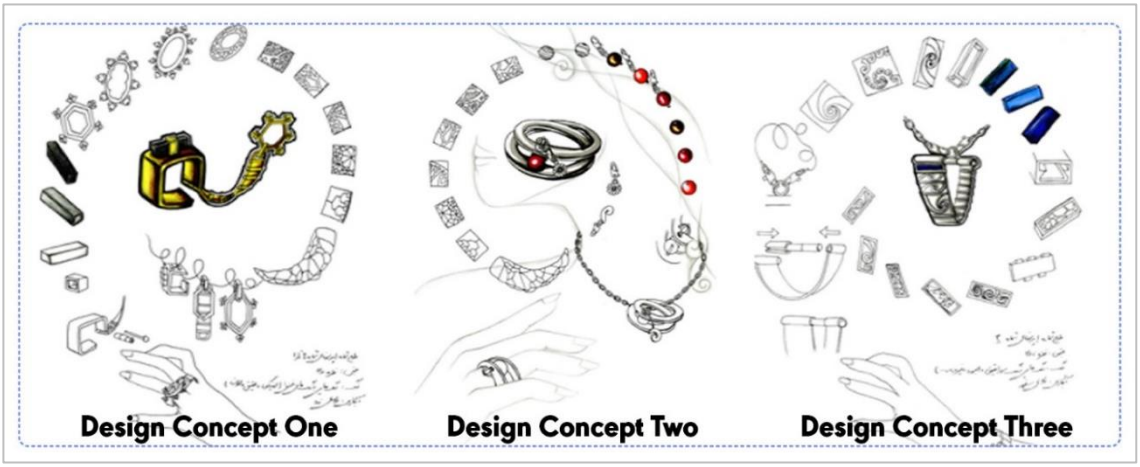

Figure 9: *Top three concepts compared to research objectives*

Following selection, the concept underwent detailed engineering, adhering to Design for Excellence (DFX) protocols, which included the Design for Maintenance (DFMai)[1] analysis. DFMai was critical for guaranteeing long-term reliability by identifying high-wear components and mandating their standardization for low-cost replacement. This process identified the Flexible Link Section (R2) and the Threaded Pin Connector (P1) as critical components.

The final design utilized advanced CAD modeling (MatrixGold) and modern vacuum casting to achieve the required intricacy and precision, successfully transitioning from digital prototype (Figures 10 and 11) to the physical artifact (Figures 12 and 13). The Bill of Materials (BOM) was optimized to only seven essential components, confirming its market feasibility (Table 8).

Note

[1] DFMai (Design for Maintenance): Analysis used to guarantee long-term reliability by identifying high-wear parts (like the Flexible Link Section R2 and Threaded Pin Connector P1) and mandating their standardization and interchangeability

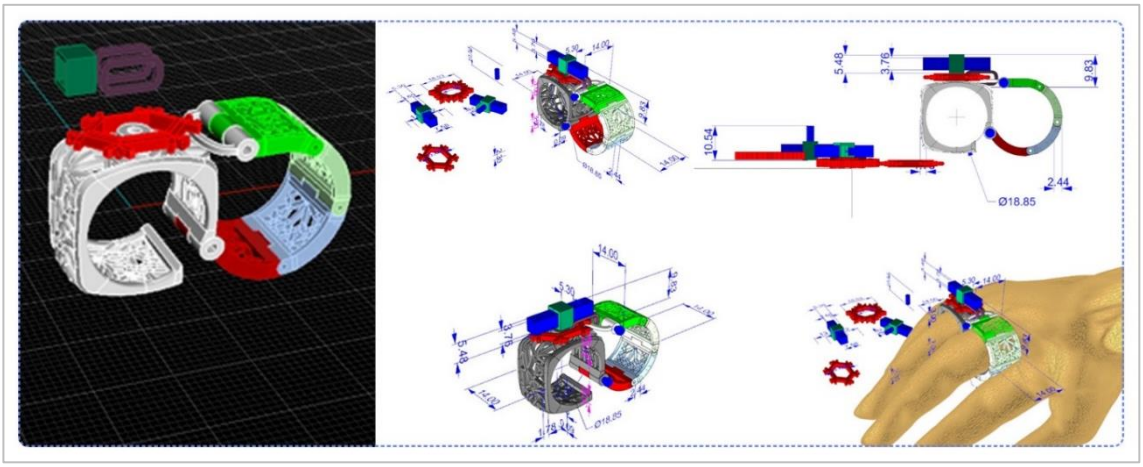

Figure 10: *Detailed CAD Rendering of the Final Design*

Figure 11: *Exploded view of the final design detailing the 7 essential components and pin connections*

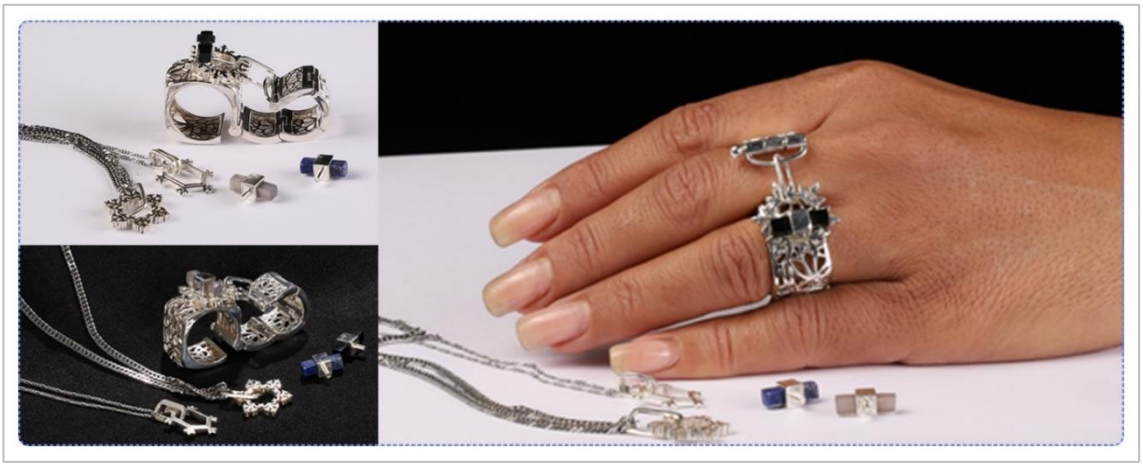

Figure 12: *Final Product Manufactured with Silver Material: "Snowflakes" Ring and Pendant*

Figure 13: *Functionality of the Final Product, Conversion Between Ring and Pendant*

Table 7: *Final AHP Weighting Summary*

Design Concept	Final Weight	Final Rank
 Design Concept One	0.7829	1st
 Design Concept Three	0.1196	2nd
 Design Concept Two	0.0985	3rd

Note: Design Concept One was mathematically selected as the optimal choice due to its highest composite weight (0.7829).

Table 8: *Bill of Materials (BOM) for the Final Design*

Row	Component Name	Quantity	Material	Production Method	Description
1	Ring Part 1	1	Metal (Platinum - Gold - Silver - etc.)	Modeling and Vacuum Casting	Allows use of various precious and semi-precious metals with threading
2	Ring Part 2 (Flexible band section)	4	Metal (Platinum - Gold - Silver - etc.)	Modeling and Vacuum Casting	Designed with fixed and movable connections to create desirable flexibility during use
3	Lever/Clasp piece (Koch Snowflake/Curve shape)	3	Metal (Platinum - Gold - Silver - etc.)	Modeling and Vacuum Casting	Has a hook shape that goes around the stone section and can be changed and set by the user
4	Snowflake Connector to Ring Part 1	1	Metal (Platinum - Gold - Silver - etc.)	Modeling and Vacuum Casting	Allows use of various precious and semi-precious metals, This piece has a threaded pin that can be opened if the user wishes, allowing the parts to be separated.
5	Interchangeable Stone Connector	3	Metal (Platinum - Gold - Silver - etc.)	Modeling, Vacuum Casting - Tapping	Allows use of various precious and semi-precious metals, has threading and a connecting pin
6	Stones	3	Various stones in neutral and cool colors	Modeling and Vacuum Casting	Various semi-precious stones like Agate, Mother of Pearl, Hematite, etc.
7	Threaded Connecting Pin	2	Metal (Platinum - Gold - Silver - etc.)	Rectangular cut	Allows use of various precious and semi-precious metals, This piece has a threaded pin that can be opened if the user wishes, allowing the parts to be separated.

Discussion and Analysis

The empirical results generated from the rigorous mixed-methodology provide decisive validation for the necessity of applying systematic design methods to address the critical economic and cultural shifts in the Iranian jewelry market.

Strategic Shift: Design Value over Commodity Value

The core finding is the quantified consumer demand for a strategic pivot in the industry's value creation metric. The AHP results, which prioritized Functionality (26.92%) and Aesthetics (30.67%) decisively over Cost/Material (23.07%) (Table 3), fundamentally challenge the traditional, commodity-centric model. This shift confirms that the emerging Iranian youth generation defines the wealth of an object not by its gold weight, but by the extrinsic value of identity, utility, and superior design. This finding moves beyond mere descriptive observation, providing a quantifiable mandate for producers: investment in design innovation is now a greater competitive advantage than investment in material stock.

Synthesis: Fractal Aesthetics in the Final Design

In the resulting product, the fractal's angular iterations are translated into the 3D-printed silver links, where the repetition of the snowflake motif creates a sense of "organized complexity", a core tenet of fractal beauty that reduces cognitive load while increasing aesthetic pleasure. This geometric precision was essential for the convertible mechanism; the interlocking fractal edges provide the necessary alignment points for the Ring-to-Pendant transformation, proving that fractal geometry is not only an aesthetic choice but a functional enabler for modular jewelry design.

Resolution of the Aesthetic and Functional Mandates

The research successfully established a new, empirically supported aesthetic language for the domestic market. The non-verbal PrEmo assessment validated the high aesthetic desirability of the Koch Fractal geometry, confirming its superior appeal compared to traditional motifs. This justified the strategic use of Fractal Aesthetics Theory (FAT), allowing the design to achieve complexity and novelty while remaining rooted in visually resonant, natural principles, thereby overcoming the "design paralysis" identified in previous studies.

Functionally, the determined priority for Ring-to-Pendant conversion demanded a robust solution. The successful engineering of the "Snowflakes" modular piece relied heavily on the application of Bionics and DFX principles. By utilizing precision-engineered micro-hinges and pins, the design ensures the reliability and repeatability necessary for long-term user satisfaction, which is essential to meet the high functional priority established by the AHP. This design resolution provides the crucial missing link in the domestic market, which currently lacks any registered, mass-produced convertible products.

Contribution to the Body of Knowledge

This study significantly advances the discourse in industrial design by offering a replicable methodological bridge between User-Centered Design (UCD) and advanced geometric theories. Unlike traditional jewelry design, which often relies on the designer's subjective intuition, this research operationalizes the ISO 9241-210 standard to transform the design process into an evidence-based science. The core contribution lies in the systematic integration of user empathy, captured through the non-verbal PrEmo instrument, into a rigorous mathematical hierarchy via the Analytic Hierarchy Process (AHP). This ensures that the final product is not merely an aesthetic object but a precise response to the cognitive and emotional "Voice of the Customer".

Furthermore, the research expands the application of Fractal Aesthetics Theory (FAT) by proving that complex geometries, like the Koch Snowflake, can be more than visual motifs; they can serve as functional frameworks for modularity. By synthesizing these fractal principles with Bionic engineering, specifically the articulation mechanisms found in arthropod joints, the study introduces a novel approach to "convertible jewelry." This contributes a technical blueprint for creating high-complexity, multi-functional products that maintain structural integrity while minimizing material mass, effectively resolving the "Tripartite Constraint" of aesthetics, functionality, and cost.

Ultimately, this work provides a strategic roadmap for the revitalization of traditional craft sectors in emerging markets. It demonstrates that by adopting a UCD philosophy, industries can pivot from a commodity-based value model (dependent on gold weight) to an innovation-centric model. This shift empowers designers to create sustainable competitive advantages through design-led differentiation, meeting the sophisticated demands of a modern, design-literate demographic.

Limitations of the Study

This study does not claim to represent the full diversity of the Iranian jewelry market. The findings are intentionally limited to a design-aware, urban youth segment with prior exposure to visual and aesthetic

education. Consequently, the results should be interpreted as indicative rather than fully generalizable, and further large-scale market studies are required to validate applicability across broader demographic groups.

Although a comprehensive economic feasibility analysis was beyond the scope of this case study, a relative cost–value assessment indicates that the optimized silver-based modular design substantially reduces material costs compared to traditional gold jewelry. Simultaneously, functional convertibility and aesthetic differentiation increase perceived user value, suggesting competitive cost-effectiveness within the contemporary affordable jewelry segment.

Conclusion

This comprehensive study successfully operationalized the ISO 9241-210 framework, utilizing a rigorous User-Centered Design (UCD) methodology to bridge the critical design gap and address the structural stagnation within the Iranian jewelry industry. The research empirically confirms a decisive paradigmatic transition among the target demographic; young Iranian women now prioritize Design Value, characterized by aesthetic innovation and functional versatility, over the traditional Commodity Value of gold mass. This shift effectively neutralizes the material-centric model that has historically hindered industrial growth.

The methodological synthesis of emotional preference mapping (via PrEmo) and computational prioritization (via AHP and QFD) proved essential in translating subjective user desires into precise, actionable engineering criteria. This approach successfully resolved the Tripartite Constraint, balancing high aesthetic resonance with mechanical performance and cost feasibility. The resulting "Snowflakes" ornament, inspired by the geometric complexity of the Koch Fractal and the articulation principles of Bionic joint mechanisms, provides a technically feasible and economically viable model for domestic manufacturers.

By validating robust mechanical convertibility (Ring-to-Pendant) through strategic material substitution and advanced manufacturing techniques, this project provides definitive proof of concept. The study concludes that proprietary, user-centric innovation, rooted in international standards, is the essential strategic pathway for fostering sustainable growth and successfully re-engaging the modern youth consumer base in the Iranian market.

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