Al-Academy Journal
Issue 112
Journal homepage: https://jcofarts.uobaghdad.edu.iq
ISSN(Online) 2523-2029/ ISSN(Print) 1819-5229
DOI: https://doi.org/10.35560/jcofarts1364

The impact of the fourth industrial revolution on the formation of metal Jewelry in the light of fractal geometry

Ghadah Abdulrahman Alfaisal [a1]

[a] *Assistant Professor of Metal Work-Product Design Department- College of Art & Design -Princess Nourah Bint Abdulrahman University*

ARTICLE INFO

Article history:
Received 22 January 2024
Received in revised form 5 February 2024
Accepted 6 February 2024
Published 15 June 2024

Keywords:
Metal jewelry
Industry 4.0
Fractal geometry
Additive Manufacturing
Advanced technology

ABSTRACT

The advanced technologies of the Fourth Industrial Revolution with its great impact on various industrial aspects came with the emergence of the term "the Fourth Industrial Revolution, as a result of the continuous technological developments that addressed many modern technologies such as additive manufacturing and augmented reality, that significantly contributed to the development of metal jewelry formation in light of molecular engineering, as the design and manufacture of metal jewelry using molecular engineering required modern and advanced technology for the ability to design and ease of implementation.

Applications of the Fourth Industrial Revolution have rapidly emerged in the design of metal jewelry through 3D printing, which was used in the formation of precious metals, and with the variety of jewelry designs and shapes that require time and effort for implementation, especially if there is a need to create special or valuable pieces or to reproduce rare pieces. Therefore, it was important to study the impact of the Fourth Industrial Revolution, the changes it brought about, and how to benefit from the advanced technologies for forming metal jewelry in light of molecular engineering. To facilitate the implementation of interwoven and complex shapes and designs inspired by molecular engineering. The research deals with the Fourth Industrial Revolution, its concept, and principles, how it appeared, and the various technologies that emerged with it, as well as its various effects, in addition to the methods of forming metal jewelry and its development from manual and traditional methods to modern and advanced methods. It also deals with molecular engineering and how to benefit from it in forming and implementing metal jewelry through the technologies of the Fourth Industrial Revolution to achieve the research goal.

[1]*Corresponding author.*
E-mail address: gaalfaisal@pnu.edu.sa

The methodological framework of the research

Research introduction:

The field of metal jewelry formation has witnessed great progress, as the technology of jewelry formation has developed tremendously, where advanced technology has played a major role in developing techniques and materials that have appeared in new and multiple shapes and forms. These forms, shapes, techniques, and materials have become an important source for the jewelry designer's creativity and the development of his innovative ideas, as the diversity like raw materials and their physical and chemical properties is matched by diversity in their formation capabilities, which allows the designer to venture into the realm of unlimited creativity. In the field of forming metal jewelry, attention should not be limited to employing the available raw materials, but rather the employment must be linked to conscious awareness and understanding of the various properties of the material as well as its formation potential. And as technological development has a great role in developing materials and technologies, it can also be a source of inspiration and creativity.

The fourth industrial revolution, Industry 4.0, has affected all aspects of life and brought about many transformations in all social, economic, cultural, and similar aspects. Products in general, including metal jewelry products, have become dependent in their composition on technologies and software through the combination of Fourth Industrial Revolution technologies and available raw materials and resources with smart systems, which changes the concept of traditional products. The increasing trend of integrating modern and disruptive technologies with smart materials and systems in consumer products has led to a new type of product, which led to the emergence of new terms, such as the term "wearable technology", which includes interactive digital jewelry. Thus, there was a shift in design research and practice from focusing on traditional issues to focusing on user-product interaction and usability.

Changing consumer preferences and increased fashion awareness have also led to increased demand for new and innovative jewelry designs. This has encouraged jewelry makers to adopt new manufacturing techniques such as computer-aided design (CAD) and laser technology to design jewelry. Many designers also use 3D printers equipped with rapid prototyping (RP) technology that allows designers to review design concepts and understand the requirements and complexity of any design of jewelry. Thus, it is possible to deal with molecular geometry, which is considered one of the design sources used in designing metal jewelry, which contributes greatly to obtaining designs that have distinctive and diverse aesthetic properties. Molecular engineering also contributes to improving the usability of metal jewelry pieces in terms of durability and lightweight, which has a significant economic impact in terms of cost savings. However, this cannot be achieved without the need for high technological methods, whether in design or implementation, through the possibility of employing the concepts of digital technology and interactive design to find new approaches that can be used in designing jewelry and opening new horizons that lead to different life and usage applications for designing contemporary jewelry.

Research problem:

The use of metal jewelry is considered one of the ancient aspects of life that have been covered by human heritage throughout its history and various civilizations, and this has been accompanied by diversity in its style as well as the methods of its manufacture. The Fourth Industrial Revolution was accompanied by a major qualitative shift in the methods of designing, as well as manufacturing and production. Therefore, the Fourth Industrial Revolution had a major impact on the formation of metal jewelry due to the ease of design and manufacturing, especially with the use of molecular engineering. Therefore, the research

problem is to benefit from the techniques of the Fourth Industrial Revolution in forming metal jewelry designed using molecular engineering.
The research problem tends to go beyond the approaches upon which jewelry design depends and to rely on appropriate ideas and concepts for interactive design and digital technology, to make jewelry design the true equivalent of the rapid technological transformations that characterize this era. There is also a clear difference between the models of digital jewelry designed by electronic engineers and industrial designers and the models designed by jewelry designers, as there are some shortcomings in each of them. Therefore, the research seeks to study the user's usability and sensual tendencies and requirements and to employ that technically and constructively.

Research aims:
- Explaining the impact of the Fourth Industrial Revolution on the formation of metal jewelry considering the fractal geometry.
- Finding the relationship between digital technology and the design of metal jewelry within the scope of the user's updated requirements .

Research Importance:
- Explaining the importance of benefiting from the technological applications of the Fourth Industrial Revolution in designing and manufacturing metal jewelry.
- Raising the economic and aesthetic value of metal jewelry using molecular engineering.
- Explaining the relationship between the design of metal jewelry in light of molecular engineering and the use of Fourth Industrial Revolution technologies in design and implementation.

Research Methodology :

The research follows the inductive method .

Research assumptions:
The research assumes that using technological applications of the Fourth Industrial Revolution in forming metal jewelry designed using molecular engineering leads to the ability to design and manufacture metal jewelry of high aesthetic and economic value.

The theoretical framework of the research

First: the formation of metal jewelry
With the development of the technology of forming metal jewelry, the techniques and materials that have appeared in new and multiple shapes and forms have become an important source for stimulating the creativity of the jewelry designer and developing his innovative ideas. The design and manufacture of jewelry appeared with the oldest forms of civilizations, and this art took many forms, starting from simple stones to advanced metalwork and precious stone pieces known in the modern era. However, advanced technology allowed designers to have easier alternatives to some of the old methods. The importance of metal jewelry and its social and economic value also changed, and with the emergence of new materials, new dimensions of the functions of jewelry emerged, followed by modern manufacturing methods and equipment. 3D jewelry design programs have also enabled designers to transfer their creativity from paper to real models in record time, in addition to the different types of precious stones so that the designer can display them before they are manufactured and print them using 3D printing techniques to ensure their suitability in terms of size and external shape. Figure (1) shows an example of the digital design of a ring and how it is shown through computer programs compared to manual sketches.

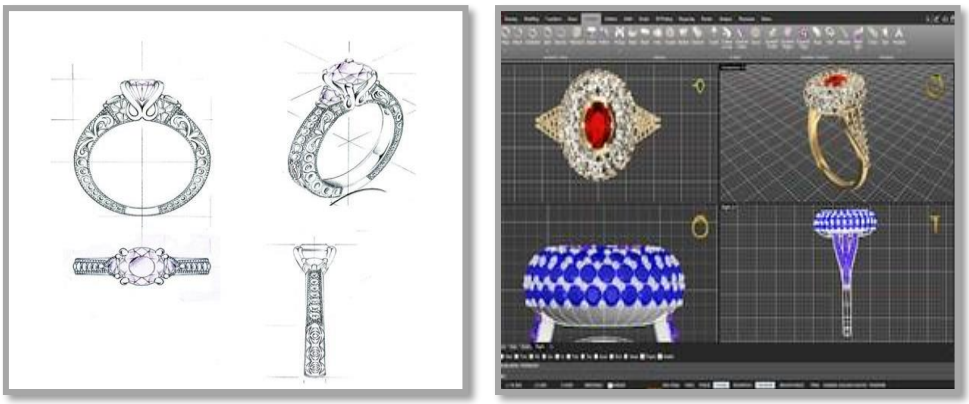


Figure (1) ring design using computer on the right and hand drawings on the left

1. Phases of the formation of metal jewelry:

The jewelry design process begins with presenting design concepts followed by detailed technical drawings to illustrate ideas, size, shape, and design options, including options related to selecting materials. When these designs are approved, these drawings shall be clarified by converting them into models, whether hand-carved or by starting to work on the digital model of the piece of jewelry. This is to imagine the way it looks before starting the manufacturing or mass production process, as shown in Figure (2), which shows the stages of forming metal jewelry.

Figure (2) Phases of the formation of metal jewelry

1-1 3D model:

Once the initial concept and sketches are completed, they are presented through 3D models that can be executed in wax, through computer-aided design software (CAD), as the digital design programs allow visualizing the design before starting the production process, and demonstrating functionality, and aesthetics, and visualization of details and materials, as shown in Figure (3).

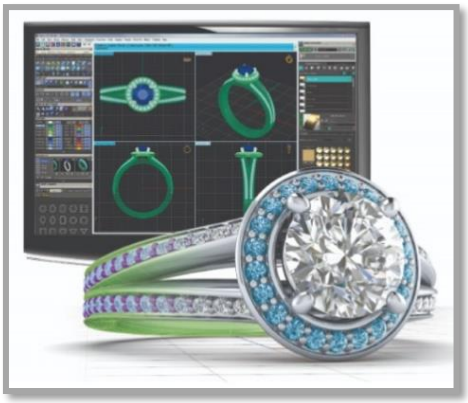


Figure (3) Computer-aided design of a metal ring

1-2 3D Wax model:

That 3d model from the last step wasn't only to see a sample ahead of time; it also served as the basis for the next step, the casting process (silver, gold, brass, or bronze). The wax model can be implemented through hand sculpting, molding, or through 3D printing as shown in Figure (4). [(1)]

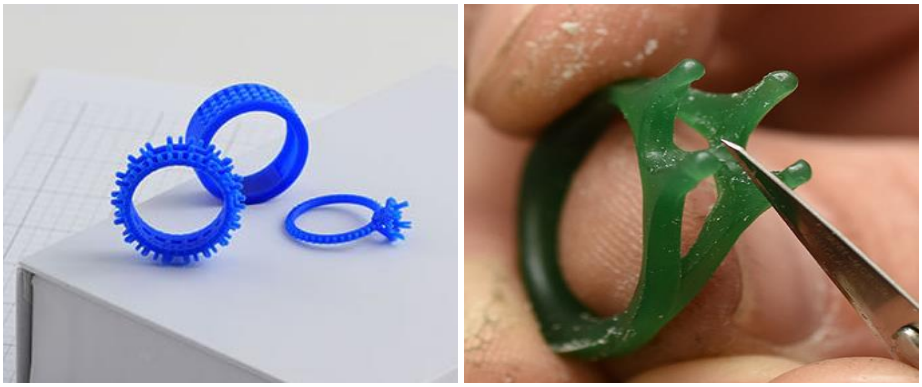


Figure (4) 3D model of a wax ring

1-3 Casting:

At this stage, the piece of jewelry goes through the casting process, and the piece begins to appear, as the wax melts and is replaced by the metal that is chosen in molten form, usually gold, silver, or platinum, as shown in Figure (5). Then the metal dries into the shape of the required piece of jewelry. This process is called lost wax casting. Figure (6) shows an example of a piece of jewelry resulting from lost wax casting.

1- Peter Vey. (2018). Jewelry Manufacturing: How it Works. https://cadcamnyc.com/blogs/our-blog/jewelry-manufacturing-how-it-works.

Figure (5) gold casting with lost wax

Figure (6) a piece of jewelry cast with lost wax

1-4 Jewelry Assembly:

After wax casting, the design is transformed through colored metals and gemstones, where the custom ornaments are polished, removing any rough areas, as shown in Figure (7). In the workshops, craftsmen use traditional skills and techniques to complete any detail on the design of the jewelry pieces, including engraving and setting of gemstones, and then a final glossy coating is applied.

Figure (7) Polishing and cleaning metal jewelry with manual equipment

1-5 The Stone Setting Process:

In this step, diamonds or other gemstones are placed on the piece of jewelry, and if there are side stones, these stones can be manually drilled for before installation using a microscope, and then each stone is placed separately, as shown in Figure (8).

Figure (8): The process of placing stones on metal jewelry

1-6 Polishing, Finishing, and Quality Assurance:

In the final stage, the polishing tool works to ensure that the metal is perfectly polished so that it is as shiny as possible, as shown in Figure (9). Any final additions such as engravings are also applied, and finally, the jewelry is inspected, and every detail is analyzed to ensure that the production was successful.

Figure (9) Polishing metal jewelry

Second: Designing metal jewelry in light of molecular geometry

Molecular geometry is a geometric structure composed of molecules (fractals), which is a group of fractals that can be defined as a very small, irregular geometric part with infinitely small dimensions, which can be composed of similar parts that are in turn composed of similar parts of the parent part. Fractal Geometry is defined as a geometric pattern that is repeated on increasingly small scales and leads to irregular shapes and surfaces that cannot be represented by Euclidean geometry. Thus, it is considered a group with infinitely complex structures and usually contains some similar measurements, that is, any A part inside it is a miniature of the whole group. [(1)]

Molecular geometry enables the designer to deal with solids, especially solids with complex structures that are difficult to build using traditional design methods. It is a flexible and modern tool in the hands of the designer to create new and innovative designs that cannot be found using traditional methods, to cope with everything new and developed.

The design of jewelry still lacks diversity based on mathematical calculations and equations, despite the quality of the resulting designs, which vary in patterns and shapes and draw inspiration from different sources of nature. Therefore, molecular engineering provides a design based on precise calculations, equations, and mathematical values, which gives jewelry designers the ability to diversify and excel in the field of metal jewelry, as shown in Figure (10).

1- Falconer, Kenneth (2003). Fractal Geometry: Mathematical Foundations and Applications. John Wiley & Sons. xxv. *ISBN 978-0-470-84862-3*.

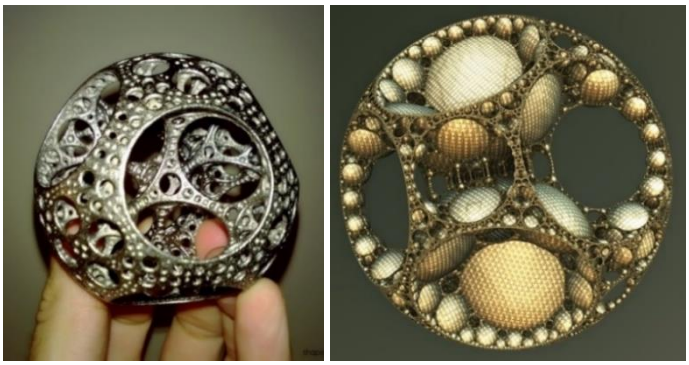


Figure (10) examples of pieces of jewelry designed according to the molecular geometry principle

1. Self-similarity in metal jewelry design:

Molecular geometry describes objects that are identical in size, or self-similarity. This means that when those objects are magnified, and their parts are viewed as an identical resemblance to the whole, the properties continue from the parts and then on to infinity. These objects are called Fractals. A molecular object can be self-similar if it undergoes a transformation in which all dimensions of the structure are modified by the same scaling factor. The new shape may be larger or smaller, or rotated or moved, but its shape remains identical. Similarity means that the relative parts of the shapes sides are still the same.

Self-similarity means the similarity between the parts that make up the shape. The irregular points themselves are similar, but on distant scales, meaning that a part of a whole is exactly like that whole, so if an integral part of the parts that make up the molecular shape is added and then enlarged several times, it eventually transpires into the original form. For example, Mandelbrot took a set of images and magnified them several times to reach the same result, as shown in the zoom sequence in Figure (11). This characteristic self-similarity of Fractals is caused by the Mandelbrot equation itself, where there are a huge number of smaller shapes resulting from the same equation, hidden everywhere within the ascending curves on the edges of the overall shape.

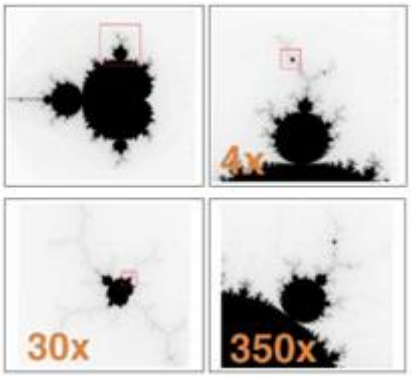


Figure (11) Proof of Mandelbrot's self-similarity

The Sierpiński triangle is the simplest example of this, as it repeats in a finite range, but has infinite properties. It begins as a triangle, and in each new iteration it creates a triangle connected to the middle point of other triangles of the same shape until we reach an infinite number of triangles, as in Figure No. (12).

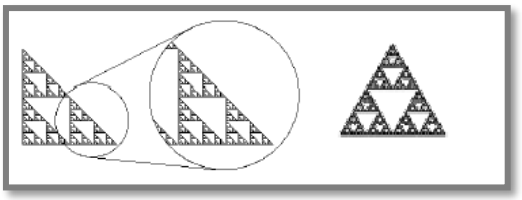


Figure (12) Sierpiński's triangle and repeating the part to form the whole.

In the field of jewelry, self-similar shapes can be observed, for example, as shown in Figure (13). The Sierpinski triangle, also called the Sierpinski gasket or the Sierpinski Sieve, is a fractal with the overall shape of an equilateral triangle, subdivided recursively into smaller and smaller equilateral triangles. The pendant represents a level four Sierpinski and contains a total of 122 triangles (including the pendant itself) CNC cut into a little 10mm radius Sterling silver pendant. The smallest triangles are barely visible. [1]

Figure (13) Self-similarity in the design of a piece of jewelry

As the concept of jewelry design changed and expanded amid changing tastes and trends, different types of designs were introduced into the jewelry industry, in line with the trend of emphasizing rapprochement with science and technology. Hence the trend of 3D printing of jewelry is inspired by molecular geometry drawn from nature. These designs can be developed through repetition, overlay, distortion, and scaling, which is a feature of the formative principle of molecular geometry.

1-1 Design by repetition:

Design by repetition means that the units are constantly repeated or stacked in a certain direction with rules and order, so that the external form of the ornament is expressed as a single three-dimensional structural form, such as merging independent spaces. The structure is formed by repetition in 3D printing jewelry structurally by repeating the same pattern as a whole. By applying the theory of molecular geometry in the field of metal jewelry design, a group of alternatives and new ideas for jewelry can be created. For example, by following some principles of molecular engineering we can obtain a suggested set of alternative ideas for designing a piece of jewelry. Figure (14) shows that the complex structure of multi-dimensional jewelry is created by repeatedly arranging the units according to a certain rule. The spatial structure can also be created by overlapping and intersecting fluctuations in a

1- Lumen Learning. (2023). Fractal Basics: https://courses.lumenlearning.com/wmopenmathforliberalarts/chapter/introduction-fractal-basics/

continuous arrangement according to the degree of angular inclination of the layers, or by joining units of triangular units of different sizes one after the other with connections, as well as repeatedly overlapping units to create an expanded image, placing spaces created by individual units side by side, or regularly arranging units and repeatedly folding to create a three-dimensional shape.

Figure 11. Chrysanthemum Pendant | Figure 12. 20 Poly | Figure 13. Polygonal Kinematics 25e | Figure 14. Spinal Cuff | Figure 15. Seed

Figure (14) various examples of jewelry designs through repetition

1-2 Organic design through overlapping:

The term interference refers to the overlapping of several layers, where each element is created as a form of beauty different from the original form or is reconstructed. Organic design by interference means that the different layers overlap to give the appearance of the jewelry a sense of depth, space, curvature, and softness. This means that it represents an organic form with a natural connection. As shown in Figure (15).

Figure (15): Examples of jewelry designs by overlapping

2. Design solutions to standardize the shape of jewelry in light of molecular geometry:

The theory of molecular geometry has proven that the molecular shape has dimensions located in an infinitesimal space consisting of a group of very dense and thin points that almost constitute a space, and they may be repeated in different proportions and dimensions. The molecular dimension has created many practical applications in analyzing the processes of Chaos Theory, as it was the first to systematically describe what they call the chaos of natural systems, which has always been a fertile source from which the designer draws inspiration for many design solutions.

The dimension calculation box is related to the problem of determining the molecular dimension of a complex two-dimensional image and is defined as the Db in the relationship: "$N(d) \approx 1/dDb$", where N(d) is the number of boxes of the linear volume to cover a set of graph points distributed in a binary graph. The basis for this method is that for Euclidean objects, this equation determines their dimensions, where several squares are needed to cover a set of points that lie on a smooth line, proportional to 1/d to cover a set of points that are evenly distributed on the diagram to infinity, By applying logarithms to the equation, we obtain: $N(d) \approx -Db \log (d)$.

The dimension calculation box can be determined using the following iterative procedures:

- Installing a grid of dimension-calculating squares over the image (which represents S1).
- Count the number of squares that contain some of the image {N(S1)}.
- Repeat this procedure and change S1 to a smaller size S2.

- Count the number of resulting squares that contain the image {N(S2)}.
- Repeat these procedures by changing S to smaller and smaller mesh sizes.

The dimension calculation box can be determined through:

$$Db = [\log (N(s2)) - \log (N(s1))] / [\log (N(1/s2)) - \log (N(1/s1))]$$

Since 1/S is the number of squares through the depth of the grid, the dimension calculation square can be applied to the pieces of jewelry as well, and it can be calculated by counting the number of squares that contain the lines of the shape within them. Figure (16) shows a procedure for determining the complexity of a leaf design using square arithmetic. The leaf image was created through computer algorithms based on iterative functional systems.

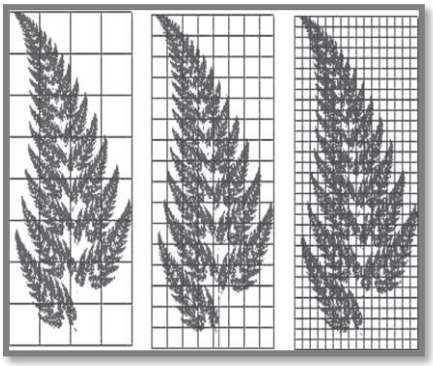


Figure (16) Applying the dimension calculation box to a leaf design

3. Challenges of designing metal jewelry in light of molecular geometry:

New types of complications have appeared in jewelry designs, as several trends have emerged in jewelry designs characterized by complex surfaces derived from observing nature and natural creatures. Which led to different and unexpected results in shapes, patterns, units, and even the functions of jewelry, which demonstrated the need to combine modern design methods and advanced technologies to overcome these complexities in design and facilitate their implementation. The role of molecular engineering, along with modern design and manufacturing techniques, comes in overcoming these complexities in designs and implementing them more precisely. Figure (17) shows a design for a piece of jewelry made of silver with a molecular geometry design. With the advent of Fourth Industrial Revolution technologies, there is no longer any difficulty in implementing any of these complex designs, also the programs for designing and codifying the shape of jewelry and calculating mathematical equations in designing pieces of jewelry have diversified. There are also various CNC digital metal jewelry forming machines that implement these designs, regardless of their difficulty, with high accuracy.

Figure (17) Printing a piece of silver jewelry with a complex design based on geometry [1]

Third: The impact of the Fourth Industrial Revolution on the design and formation of metal jewelry

The Fourth Industrial Revolution (4IR) is the fourth major industrial era since the First Industrial Revolution in the 18th century, characterized by the integration of technologies that blur the lines between the physical, digital, and biological domains, and the breakthrough of emerging technology in several fields, including robotics, artificial intelligence, nanotechnology, the Internet of Things, and 3D printing. The Fourth Industrial Revolution is based on the digital revolution, which represents new ways in which technology becomes an integral part of societies and even the human body.

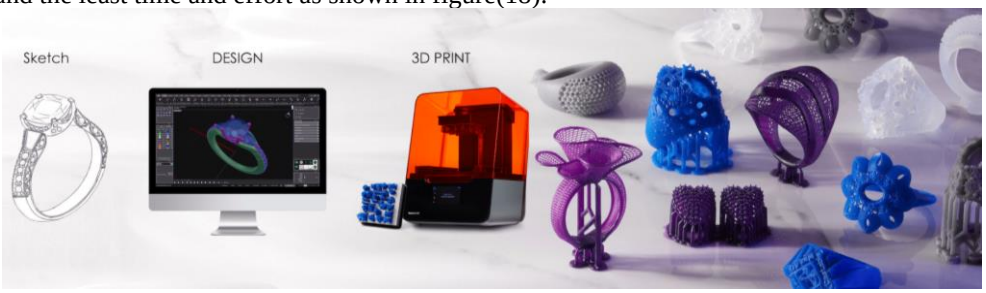
The Fourth Industrial Revolution has affected the processes of designing and manufacturing metal jewelry, starting with the use of programs dedicated to designing and processing jewelry, passing through modern digital manufacturing techniques that facilitated the implementation of jewelry designs with high accuracy, especially complex jewelry-inspired by molecular engineering designs, all the way to developing the functions of jewelry, introducing technology, and relying on AI and IoT techniques, such as digital jewelry and wearable jewelry.

Jewelry designers have turned to using computer-aided design and manufacturing techniques to give life to their ideas in the form of 3D models to achieve the maximum levels of design and creativity.

1. Digital transformations in jewelry design in light of molecular geometry:

Digital transformation in jewelry design has become important for several reasons, the most important of which is saving time and cost, as the jewelry designer can change the design on the computer several times until he reaches the final design that suits his taste or the taste of the customer. In addition to the possibility of easily accessing several alternatives for each design through developed computer programs, which saves time, money, and effort. For example, the JEWELCAD PRO program is dedicated to jewelry design, which includes some ready-made templates that help the designer save time and easiness in design and implementation, in addition to the program's design tools, which help the designer to be creative to create wonderful shapes and creative ideas. AI such as expert systems (ES) use human knowledge to solve problems that typically require human intelligence and design thinking and can also help designers improve the design and devise new designs based on existing models.

Technology also helps designers to liberate designs and reach high levels of creativity by providing modern manufacturing methods such as CNC computer numerical control machines, which have enabled designers to produce many complex designs with accuracy, high quality, and the least time and effort as shown in figure(18).



1-Andersson, J. (2023). Fractal Mathematics. https://www.shapeways.com/product/QSDFYXQ2D/dissecteddragonpendant?optionId=61920291&li=shops.

Figure (18) A variety of jewelry produced through 3D printing

1-1 Using computers to design metal jewelry:

The digital revolution has affected all aspects of life and has brought about many transformations in all social, economic, cultural, etc. aspects. Recently, most products, including metal jewelry products, generally depend in their composition on hardware and software through the combination of digital technology and the available raw materials and resources with smart systems to design and produce more functional and interactive jewelry pieces. Two- and three-dimensional computer design programs have helped employ creative skills and abilities to reach complex, more aesthetic, functional and kinetic forms that mimic contemporary reality and meet the desires of users. Computer design programs also provide the ability to save digital data for images and colors and process them with what distinguishes them of accuracy and speed of completion. Below is a review of some types of design software that can help jewelry designers accomplish their tasks more effectively.

1-1-1 Wizegem software:

The Wizegem software provides useful solutions for hobbyists and non-designers who want to design personalized jewelry, as it provides the ability to select jewelry elements, with simple clicks, and to customize them, to provide elegant jewelry designs ready for production or using 3D printing. As shown in Figure (19). (1)

Figure (19): An example of designing a piece of metal jewelry using Wizegem software

1-1-2 Matrix Gold software:

The Matrix Gold software provides the opportunity to explore distinctive creative dimensions in the design of metal jewelry. It fulfills the passion and helps in creating distinctive metal jewelry from the beginning, as it is considered one of the most popular programs in the field of 3D printing. Figure (20) shows some pictures of the designs that are produced using Matrix Gold software. (2)

1- Thimmesch, D. (2015). Design and 3D Print Jewelry in Precious Metals. Retrieved from https://3dprint.com/38343/3d-print-jewelry-wizegem/.
2- Matrixgold software website (13-04-2022): https://gemvision.com/matrixgold.

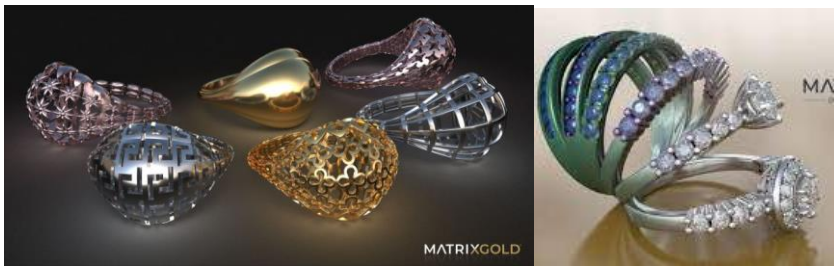


Figure (20) Examples of complex metal jewelry designs using the Matrix Gold software

1-1-3 3Design software:

3Design is a software for designing and creating jewelry that has proven its efficiency all over the world by jewelry designers. It is characterized by a simple and easy-to-use interface and contains many tools. Figure (21) shows an example of designing metal jewelry pieces using the 3Design software. (1)

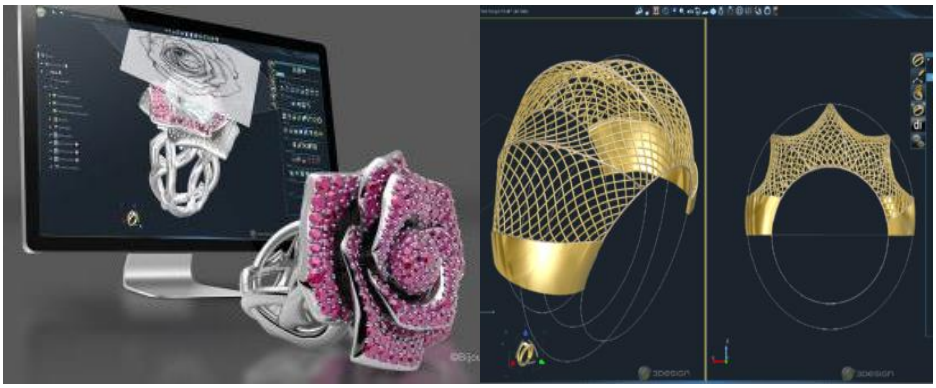


Figure (21): An example of designing metal jewelry pieces using the 3Design software.

1-1-4 Jewel CAD Software:

It is a program specialized in designing jewelry that has gained popularity. It is characterized by easy control and a flexible user interface equipped with many tools that give a lot of freedom to the user, allowing the creation of beautiful designs. It also contains many features such as: Editing the curve and point, generating a group of stones, and producing image-like displays, which is a helpful tool in designing rings or necklaces containing gemstones. It allows the possibility of calculating the number and weight of stones, and it does not require experience to use it as it is an easy program to learn and apply and provides the possibility of placing the design on CNC machines and creating prototypes that match reality as shown in Figure (22). (2)

1- 3Design software solution. (2023). About 3Design website: https://3design.com/en/.
2-Romanoff International Supply Corporation. (2023). Jewel cad software. https://www.romanoff.com/3d-manufacturing/cad-software/jewel-cad.html.

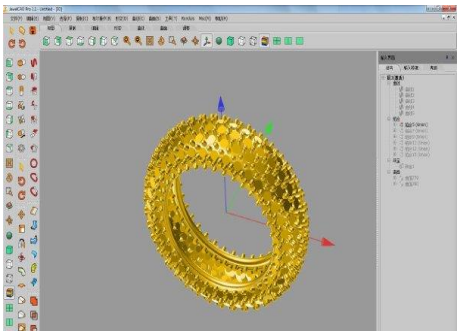


Figure (22): designing a piece of metal jewelry using the Jewel cad program, following an iterative pattern

1-1-5 Zbrush software:

Zbrush is a great solution for creating professional and distinctive jewelry designs. It is used by many jewelry designers around the world. It is ideal for creating detailed jewelry designs and creating complex models such as jewelry designs based on molecular geometry. It allows the possibility of designing rings, necklaces, bracelets, and all jewelry designs and adding many distinctive and professional details as shown in Figure (23). [1]

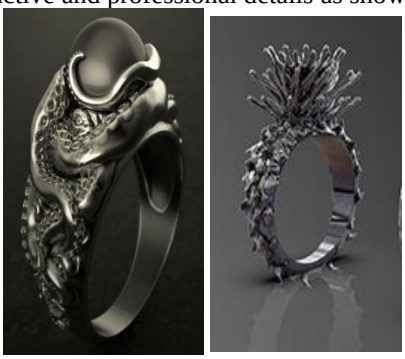


Figure (23): Design for metal jewelry pieces using Zbrush software

1-1-6 RhinoGold software:

Rhino3D is especially popular in architecture and interior design, and is available in several versions, including RhinoGold, which specializes in jewelry design. This program is considered one of the best programs in designing jewelry, as it provides a set of ready-made models and components for designing rings, earrings, bracelets, etc. Figure (24) shows following the molecular pattern to design a ring using the RhinoGold software. [2]

1- Zbrush software: https://pixologic.com/.
2-Software Informer. (2023). Rhinogold software.
https://rhinogold.software.informer.com/4.0/

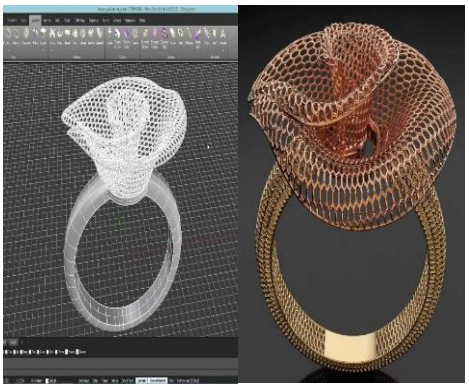


Figure (24) Design of a ring using the RhinoGold software, following the molecular pattern

1-1-7 Fractint software:

Fractint offers many types of jewelry designs based on the principle of molecular geometry, complexity, and creating a repeating geometric pattern on computers. Through it, different types of fractal jewelry can be drawn, and dimensions and mathematical calculations can be processed using computers as shown in Figure (25). [1]

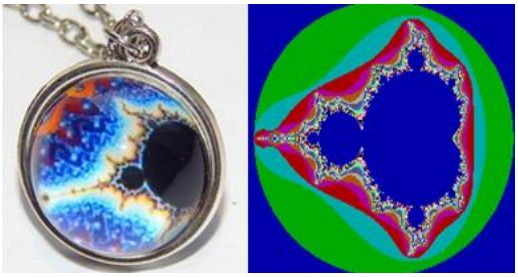


Figure (25) Using the Mandelbrot equation in designing a piece of jewelry

1-1-8 Aura Pendant application:

The Aura Pendant application is an application that turns human emotions into jewelry designs that can be printed. The topic may seem like science fiction, but engineers at Estudio Guto Requena in Brazil have developed a technology that can 3D print emotions in the form of unique pendants using smartphones. This is done through three different sensors to capture heartbeat, sound, and brain activity while the user tells his own love story. Feedback is then collected and used to draw a map to design a piece of jewelry that expresses his feelings. Figure (26) shows a design for pieces of metal jewelry stemming from emotional experiences. Therefore, many complex shapes and designs of jewelry can be produced and formed in precious metals such as gold using 3D printing machines through emotions.

1-Fractint Development Team. (2023). *What is fractal geometry*. https://web.archive.org/web/20161001153925/http://fractint.org/

Figure (26) Design for metal jewelry pieces using the Aura Pendant application

The idea of the application is that when the body physically reacts to emotions, it generates stimuli that modify the sound, heart rate, or brain wave patterns. The software interface is designed so that it can interpret the data collected from the sensors in the smartphone and model the data in the particle system to create a single language, so that each particle has a different behavior that is changed by the sensor data. For example, the sound sensor is responsible for the speed of the particles, the heart rate responds with the change in thickness, and the brain waves cause particles to be attracted or repelled, as shown in Figure (27).[1]

Figure (27) is an example of converting data generated from human emotions into the design of a distinctive piece of jewelry

1-2 Augmented reality applications in metal jewelry design:

Augmented reality technology has brought about many changes in all areas of life, allowing new fields for metal jewelry designers to experiment with new and more effective methods in the field of metal jewelry design. Technology has become an integral part of societal development and there has been a digital expansion of all products. It is possible to simply conduct a digital scan of any shape, regardless of its complexity, and turn it into a printed piece of jewelry using one of the distinctive metals. Augmented reality technology has proven very effective in designing and manufacturing metal jewelry, starting with robots that cast and manufacture jewelry pieces, through artificial intelligence technology that predicts taste and fashion trends, and all the way to virtual reality mirrors that are used in trying on jewelry pieces, as the technology works to automate, customizing and accelerating every aspect of the metal jewelry industry, as shown in Figure (28).

1- Kety S. (2017/06/11). *3D printed Aura pendant*. Retrieved from https://3dadept.com/you-could-customize-your-love-story-with-3d-printed-aura-pendant/.

Figure (28) Using augmented reality in the user experience of metal jewelry designs

2. Digital transformations in metal jewelry manufacturing:

The term Industrial Revolution includes many technological developments consisting of a combination of advanced manufacturing systems, advanced digital technologies, Cyber-Physical Systems (CPS), and the Internet of Things (IoT). The Fourth Industrial Revolution was preceded by three industrial revolutions. As shown in Figure (29), it is:

- The First Industrial Revolution was based on the invention of the steam engine, which allowed the use of steam and water energy to mechanize production.
- The Second Industrial Revolution was based on replacing steam with electrical energy and increasing production.
- The third industrial revolution was represented in the use of electronics and information technology to automate production.

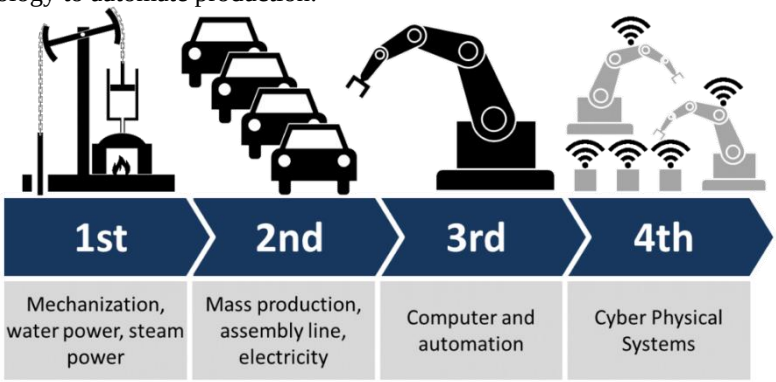


Figure (29) Industrial Revolutions (credit to Christoph Roser)

The developments that occurred in the Fourth Industrial Revolution have affected the design and manufacturing process, which is defined as a philosophy in which advanced technology is used in the early stages of design- to design parts and products that can be produced more easily and more economically until the stages of usage. Therefore, the fourth industrial revolution, Industry 4.0, targets an aspect of the design process in which issues related to the design and manufacture of the designed product are considered explicitly to reach the optimal design, which revolves around tooling costs and time required, processing or control costs,

assembly time and human factors during the design process.(1) This is confirmed by the Fourth Industrial Revolution, Industry 0.4, by using technology to carry out complex and unconventional design and manufacturing processes.

As a result of the rapid change in the global economy and market requirements, has led to an increasing demand to produce new and smart products, and recent technological developments, have led to major changes in the process of designing and developing products in terms of the ways and methods used.

Therefore, the concept of the Fourth Industrial Revolution, Industry 4.0, is concerned with introducing new technological trends and tools that lead to innovative processes and new ways of integrating information, such as using virtual and placed prototypes to achieve product visualization and design together. The changes addressed by the fourth industrial revolution, Industry 4.0, in the product life cycle, were the emergence of advanced digital tools to develop the design of products that include advanced computing platforms, such as virtual and augmented reality by combining digital and physical models. These technologies are rewriting the rules of product development processes, providing new opportunities for product development, and combining the strengths of optimized manufacturing with cutting-edge internet technologies.(2)

It is therefore not surprising that the Fourth Industrial Revolution is receiving increasing attention particularly in Europe, but also in the United States, which has been coined as the Industrial Internet. (3)

The Fourth Industrial Revolution includes a group of technologies that involve both products and processes, integrating the digital, virtual, and physical world with 17 trends, each of which has led to a qualitative shift in the product design and development program. These technologies have influenced the design and manufacturing of the product, as more than 70% of the costs of manufacturing the product are determined early in the stage of developing the concept (visualization) of the product. Organizations that have applied Fourth Industrial Revolution technologies to their products have realized significant benefits, through reductions in costs and time while making significant improvements in quality, reliability, serviceability, product line breadth, delivery, customer acceptance, and overall competitive position. (4)

These basic techniques have led to advances in technology that form the basis of the fourth industrial revolution, Industry 4.0 and are already used in design and manufacturing, resulting in unique jewelry products, over time they can be manufactured using a wide range of methods. For example, 3D printing not only allows for rapid, low-cost prototyping but also the production of finished products from metal. However, it is the CNC (which stands for computer numerical control) technology that seems to be making the biggest boom in the jewelry industry, offering many solutions to the problems faced by jewelry makers.

Since metal casting is one of the most common methods of manufacturing jewelry, manufacturers tend to focus on improving the process of making master models to speed things

---

1- Blanchet, M. Rinn, T. Thaden, G. Thieulloy, G. (2014). *Industry 4.0 - Potentials for Creating Smart Products: Empirical Research Results*. International Conference on Business Information Systems, LNBIP.

2- Blanchet, M. Rinn, T. Thaden, G. Thieulloy, G. (2014). *Industry 4.0 - Potentials for Creating Smart Products: Empirical Research Results*. International Conference on Business Information Systems, LNBIP.

3- Annunziata, M. Evans, P. (2012). Industrial internet: Pushing the boundaries of minds and machines. Gen. Electr.

4- Anderson, David M. (2008). Design for Manufacturability & Concurrent Engineering: How to Design for Low Cost, Design in High Quality, Design for Lean Manufacture, and Design Quickly for Fast Production. CIM Press.

up. Instead of manual wax carving, manufacturers use CNC machines to create a wax version of a piece of jewelry using CNC technology. It allows the production of more complex and precise geometric shapes compared to a hand-carved piece. For example, engraved details can be made before casting. Machines also work faster but require the creation of a CAD file for the product to be manufactured.
Modern technologies, such as 3D printers and multi-axis engraving and cutting devices, such as milling and lathing, have affected all industries, and in the world of jewelry, this development was not only a factor in reducing the cost of manufacturing and increasing the amount of production, but it also increased the creativity of jewelry manufacturers to focus on design instead of wasting time effort in doing traditional manual work.

2-1 3D printing

3D printing has grown exponentially as the most popular new technology in manufacturing industries, providing easier and faster alternative solutions for prototyping as well as manufacturing metal jewelry pieces. 3D printing allows the manufacture of small and complex metal parts with high quality and speed, which improves the quality of designs and facilitates modification. 3D printers can be used to make cost-effective plastic models of precious jewelry pieces before the final design is produced or used to manufacture casting molds. It is also used in the direct manufacturing of jewelry pieces made of silver, gold, or platinum, as 3D printing techniques allow designers to use complex shapes and complex fractal designs that are impossible to manufacture using traditional manufacturing techniques. Figure (30) on the right shows a design for a necklace inspired by the fractal, and on the left is a sterling silver necklace with a detailed design inspired by ammonites, by the designer Janelle Wilson, whose artistic name is Unellenu. Both designs were implemented using a 3D printer.

Figure (30) 3D printing of fractal-inspired earrings and a necklace, design by Unellenu [1]

2-2 3D Scanner:

3D scanning is the process of digitally analyzing an object to obtain three-dimensional information about its shape. 3D scanning of metal jewelry offers many advantages, as this process allows for a detailed CAD file of a piece of jewelry, capturing a high level of detail, and then improvements to the process of creating new or improved jewelry pieces. [2]
It is a fast, highly accurate and cost-effective way to capture rare and valuable pieces of jewellery, store and archive these digital files for later use, modification, etc., or to repair or

1-Ammonite pendant. (2023). silver and 18ct gold Fractal geometry.
https://www.unellenu.com/designs/ammonite-pendant-silver-and-18ct-gold/
2-B9Creations. (2023).3D Scanner technology. Retrieved from
https://www.b9c.com/products/b9-scan-500.

copy an item, It is also possible to create a new design based on an existing piece of jewelry, where a 3D scan of the original model is performed and edited using a CAD program, which can be printed using a 3D printer. Figure (31) shows an example of a method for copying a piece of jewelry, modifying the design, and manufacturing it using a 3D printer.

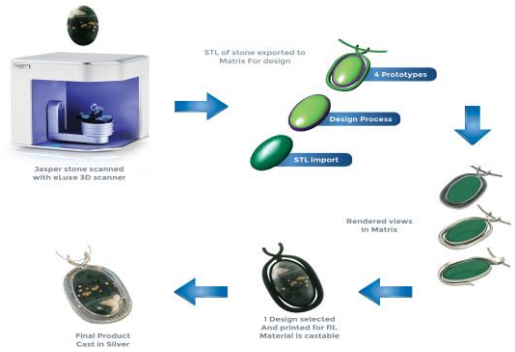


Figure (31) 3D jewelry scanning and printing workflow using a 3D printer and casting

2-3 Engraving machine:

Recessed engraving machines for metals are one of the most important applications of CNC computer numerical manufacturing machines, through which designs and decorations can be carved on the metal, or words or other engraved patterns, which play a major role in the design aspect of jewelry pieces. Digital engraving machines enable the production of accurate designs, and visible patterns, as shown in Figure (32).

Figure (32) Recessed engraving with a laser engraving machine

2-4 Forming metals using a CNC laser cutting machine:

Digital laser machines can also make metals with the same manual techniques, but more accurately and with higher quality, and also more quickly. Names, pictures, logos, trademarks, etc. can also be engraved very quickly and accurately, as the machine performs the cutting and engraving process or engraving, as shown in Figure (33).

Figure (33) Cutting or engraving jewelry it with a CNC laser machine

2-5 Forming jewelry using a CNC milling machine:

Milling machines use rotary cutting tools to carve jewelry pieces from materials such as wax, metal, and plastics, allowing the design model to be easily tested before final casting. They can also be used to produce finished designs by milling metals such as silver or gold. Three-axis, four-axis, and five-axis machines are available and can give the user more capabilities and flexibility. These advanced devices can reach almost every angle of the model, allowing detailed shapes to be produced without any manual intervention, as shown in Figure (34).

Figure (34): An example of using a digital milling machine to form gold

2-6 Forming metal jewelry using a CNC lathe machine:

The CNC lathe machine works with the same mechanism as the traditional lathe, but in digital form through the computer. The lathe mechanism forms metals through the rotation of the items. Due to the prevalence of circular shapes for most pieces of jewelry, from rings to bracelets, CNC lathes are highly suitable for metal jewelry shaping applications, as small CNC lathes allow detailed designs to be carved or engraved into pieces of metal jewelry, as well as performing polishing operations, as shown in the figure (35), these lathes work with a variety of metals from precious metals to stainless steel and provide a level of precision and uniformity not encountered by the human hand**.** [1]

1- OMAR URIARTE, CNC MACHINING (15-Aug-2021):
https://www.cncmasters.com/cnc-machining-is-popular-among-jewelry-makers/

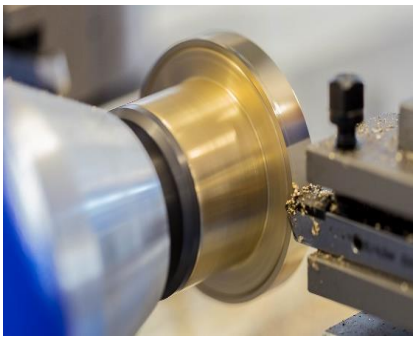


Figure (35) Forming metal jewelry pieces using a CNC lathe machine

outcomes and recommendations

Outcomes:

- The emergence of Fourth Industrial Revolution technologies has made it easier to form metal jewelry using molecular engineering.
- The use of Fourth Industrial Revolution technologies has led to the ability to achieve the personal and individual desires of users in the field of metal jewelry formation.
- The use of modern molecular engineering applications and the use of computers to implement complex designs has resulted in raising the aesthetic and economic value of metal jewelry.
- Learning about the technological applications of the Fourth Industrial Revolution contributes to reducing manufacturing costs and increasing productivity for products in general and metal jewelry products in particular.

Recommendations:

- Emphasizing the necessity of benefiting from modern applications of molecular engineering in light of the impact of the Fourth Industrial Revolution to raise the aesthetic and economic value of metal jewelry.
- Conducting more scientific studies on the technological applications of the Fourth Industrial Revolution and what it can offer to the field of product design in general and the field of metal jewelry in particular.

Conclusion

The Fourth Industrial Revolution has led to major changes in the design and manufacture of metal jewelry, making it possible to create more creative, innovative, and economical jewelry than before. New materials are constantly being developed for use in the manufacture of metal jewelry. These materials are stronger, more durable, and have better properties than the traditional ones and also less expensive. The use of 3D printing leads to the ability to create shapes that are more complex and more beautiful than those manufactured using traditional methods.

The use of computers and artificial intelligence can also help designers to design more creative and innovative jewelry, especially with the ease of using molecular engineering in design, as well as the use of robots in manufacturing jewelry with high accuracy and greater efficiency, which improves quality and reduces cost.

Thus, the impact of the Fourth Industrial Revolution on the formation of metal jewelry becomes clear, as it is expected that the impact of this revolution will continue to cause significant and continuous changes in the formation of metal jewelry in the future.

References:

1. B9Creations. (2023). *3D Scanner technology*. Retrieved from https://www.b9c.com/products/b9-scan-500.
2. 3Design software solution. (2023). *About 3Design*. website: https://3design.com/en/.
3. Anderson, David M. (2008). *Design for Manufacturability & Concurrent Engineering: How to Design for Low Cost, Design in High Quality, Design for Lean Manufacture, and Design Quickly for Fast Production*. CIM Press.
4. Kety S. (2017/06/11). *3D printed Aura pendant*. Retrieved from https://3dadept.com/you-could-customize-your-love-story-with-3dprinted-aura-pendant/.
5. Blanchet, M. Rinn, T. Thaden, G. Thieulloy, G. (2014). *Industry 4.0 - Potentials for Creating Smart Products: Empirical Research Results*. International Conference on Business Information Systems, LNBIP.
6. Thimmesch, D. (2015). *Design and 3D Print Jewelry in Precious Metals*. Retrieved from https://3dprint.com/38343/3d-print-jewelry-wizegem/.
7. Annunziata, M. Evans, P. (2012). *Industrial internet: Pushing the boundaries of minds and machines*. Gen. Electr.
8. Lumen Learning. (2023). *Fractal Basics*. Retrieved from https://courses.lumenlearning.com/wmopenmathforliberalarts/chapter/introduction-fractal-basics/.
9. Ammonite pendant. (2023). *silver and 18ct gold Fractal geometry*. Retrieved from https://www.unellenu.com/designs/ammonite-pendant-silver-and-18ct-gold/
10. Fractint Development Team. (2023). *What is fractal geometry.* https://web.archive.org/web/20161001153925/http://fractint.org/
11. Von Scheel, H. (2023). *The Fourth Industrial Revolution*. Retrieved from http://von-scheel.com/masterclass/
12. JewelCAD Pro. (3-Jan-2022). *A professional environment for design and modeling*. https://jewelcad-pro.software.informer.com/
13. Romanoff International Supply Corporation. (2023). *Jewelcad software*. https://www.romanoff.com/3d-manufacturing/cad-software/jewel-cad.html.
14. Vey, P. (2018). *Jewelry Manufacturing: How it Works*. https://cadcamnyc.com/blogs/our-blog/jewelry-manufacturing-how-it-works.
15. Andersson, J. (2023). *Fractal Mathematics.* https://www.shapeways.com/product/QSDFYXQ2D/dissected-dragon-pendant?optionId=61920291&li=shops.
16. Zahran, A. Yousef, O. (2022), *The Role of Industry 4.0 Technologies in Design Process Management*. International Design Journal. Vol. 12 No. 2. (March 2022) pp 299-311.
17. Gemvision. (2022). *Matrixgold software*. https://gemvision.com/matrixgold.
18. Uriarte, O. (2021). *CNC Machining*. https://www.cncmasters.com/cnc-machining-is-popular-among-jewelry-makers/
19. Poli, C. (2001). *Design for Manufacturing: A Structured Approach*. 1st edition, Butterworth-Heinemann. ISBN 9780080503943.
20. Software Informer. (2023). *Rhinogold software*. https://rhinogold.software.informer.com/4.0/
21. Zbrush software. (2023). *Jewelry design. From The Workflow Of Dreams To Works Of Art*. https://pixologic.com/.