# COPYRIGHT PROTECTION IN ADDITIVE MANUFACTURING

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Additive Manufacturing (AM) has been proven to be a significant development for production as well as become an attractive alternative manufacturing process compared with Subtractive Manufacturing (SM). This can be explained by the massive advantages of AM including mass customisation, less material wastage and ability to create prototypes. However, in order to make use of the AM process, firms, developers and designers require a virtual sharing platform, which can be used to trade designs and make the whole industry better off. This desire requires ways to protect the models and designs from digital thieves. Moreover, internal transactions of designs inside a single firm also require a significant level of security. So, this paper offers different ways of protecting both physical models and virtual designs. The solutions in this paper can be used to ensure the integrity of the physical products and virtual designs during different kinds of transactions.

**KEYWORDS**

Copyright, additive manufacturing, originality, blockchain, and models protection.

## 1. INTRODUCTION

### *1.1. Additive Manufacturing*

Additive Manufacturing is a way of manufacturing process in which the three-dimentional (3D) products will be created with multiple stacking layers of material. A computer software design and control the whole process. Additive Manufacturing techniques are also called Solid Freedom Fabrication. Additive Manufacturing techniques have been used since the 1980s to create prototypes. This manufacturing procedure helps simplify the process of creating complicated product structures. With the help of Additive Manufacturing, designers and producers can have a physical model of final product without wasting time, money and effort on using specific tools [Shashi 2017].

At the beginning, designers and engineers create computer-aided design illustrating the object to be produced. After that, the 3D objects are sliced into layers with even thickness, creating a 3D data set of contoured virtual slices. Then this set is submitted to a machine that executes two basic steps each layer to form a physical product. First, each layer is processed according to the designed contour and thickness. This can be done in many ways based on the technique of the machine. Second, each layer is bonded to the previously existing layer, making the top layer of the unfinished product. These two basic steps are repeatedly done from the first layer to the final layer in every Additive Manufacturing (AM) machine in the world. The difference between machines is only the way that each step be done, which relate to the technique of the machine (see Fig. 1) [Raos 2013].

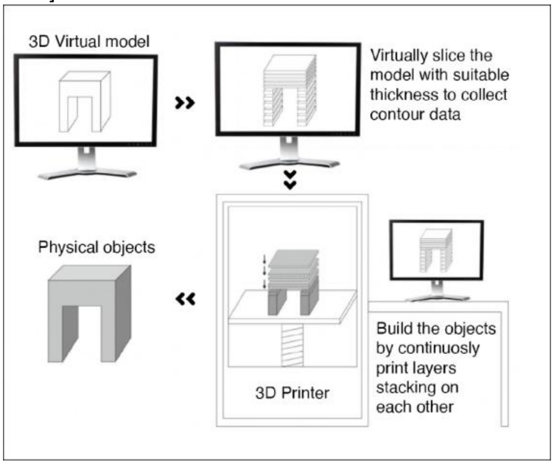


**Figure 1.** Basic principle of additive manufacturing process [Raos 2013].

### *1.2. Metaverse*

The metaverse is a seamless and ongoing blend of the physical and virtual worlds, made possible by the integration of advanced technologies like virtual reality (VR) and augmented reality (AR). It provides a multisensory experience that allows people to interact with both digital objects and others in a networked immersive environment. Essentially, it's a connected and interactive virtual space where users can communicate in real time and engage with digital content in a lively and seamless manner. This concept is made possible by the convergence of various technologies that enable users to experience an intangible environment in a tangible way. [Mystakidis 2022].

Although the metaverse was originally designed to enhance social media, its potential benefits extend to a wide range of industries and sectors, such as industry, commerce, society, education, healthcare, the military, and government. The lack of an immersive encounter is a challenge faced by online remote access and control systems, and this is especially significant for remote automation systems that use Supervisory Control and Data Acquisition (SCADA) or Programmable Logic Controller (PLC) technology. Additionally, there are various areas that require more innovation in order to fully leverage the metaverse's potential, such as fitting clothing. The ability to understand 3D visualization has many potential uses, including in medical, engineering, and architectural education, remotely operating unmanned vehicles in the air, sea, or on land, enjoying immersive digital entertainment, and improving perception for commercial real estate or architecture.

### *1.3. Metaverse and Additive Manufacturing*

The application of AM does not stop at creating prototypes only, the procedure can be used to optimize the economy as well. Economy nowadays is very flexible with new products and trends every single day, so the manufacturers are required to update the products every day. Unlike Traditional Manufacturing, which requires the designer to work with the manufacturing engineer to form the prototype as well as remodify the production line in order to adapt to the market requirement. AM can change the way economists and entrepreneurs make their decision. By applying AM, they can make prototypes to measure the market size, they can buy designs online or from freelance designers, they can focus more on the sale and analytics rather than the way to create the products. From the designers' perspective, they can work on their 3D data sets to design the products in their mind, which releases them from working with only a single boss or firm. These designs can be sold on some trading or auctioning platforms and help designers make a huge amount of money, especially with the rapid growth of non-fungible token (NFT) and cryptocurrency market.

However, AM has some drawbacks as well. With the point view of the designers, they lack the realistic view of their designs in some specific categories including medical and military fields. Therefore, the metaverse can be a valuable solution to the challenges faced by online remote access and control systems. It provides a digital environment that expands the possibilities in various fields beyond measure. One of the key advantages of the metaverse is the concept of Digital Twins (DTs), which can enhance the remote operation, control, and experimentation of machines, vehicles, or physical objects with better coordination and visualization skills can benefit not only the military but also the industrial domain [Priya 2022]. The metaverse's 3D visualization capabilities can lead to better accuracy and understanding of the context, which can be useful for both educational and entertainment applications. Moreover, the metaverse platform also has the capacity to facilitate innovative strategies, like remote robotic control utilizing AR and remote surgery with AR assistance [Ranaweera 2020].

In addition to the aforementioned benefits, the metaverse also presents an opportunity to address some of the challenges faced by certain technological concepts such as cryptocurrency [Bouri 2021], digital-biometrics [Samatas 2022], and explainable artificial intelligence (XAI) [Koeppe 2022]. These notions face challenges when put into practice, such as compatibility with existing systems, interoperability, legal and ethical discrepancies. However, given that the metaverse is a recent development, incorporating these concepts during its design stage could lead to increased security and privacy for its users and an improved overall service experience.

## 2. COPYRIGHT ISSUES IN ADDITIVE MANUFACTURING

Additive Manufacturing (AM), also known as 3D printing, has revolutionized the manufacturing industry by enabling the production of complex and customized objects with greater ease and at a lower cost. However, this technology has also brought with it several legal and ethical issues related to copyright protection. A company in Watertown, Massachusetts, the USA named Markforge mastered the 3D printing technique for metal materials and they even sell plenty of tools for different firms and individuals to print out metal objects [Markforged 2022]. This definitely is a positive improvement for 3D industry. But besides that, the risk of 3D counterfeiting is more severe than ever before. With the existence of scanning technology, a 3D object can be scanned and turned into Computer Aided Design (CAD) program easily [Khalili 2007]. In the case of professional corporations, this action is definitely illegal. But for individuals, unprofessional firms, the license awareness is not high, so they are able to accidentally use this technology to recreate the 3D object, which harm the creator as well as the manufacturer because it will lower the sales of the objects. Moreover, some opening platforms like Thingiverse allow users to download STL (stereolithography) file of a 3D object, which can be used to import into the printers to recreate the objects. This leads to plenty of stories related to copyright issue, one of which even includes Disney. Thus, the ability to create copies of objects using AM raises concerns about the infringement of intellectual property rights, particularly in cases where the designs are protected by copyright. While copyright law has been adapted to deal with digital piracy, it is still unclear how it can be applied to 3D printing.

**Figure 2.** The Physical product of Andrew Martin (Left) and the Physical product sale in Disneyland (Right) [Joris 2022].

On 19th February 2022, artist Andrew Martin posted a Tiktok video to accuse Disney of stealing his design and mass-producing to sell the object as a souvenir (Fig. 2). Disney has not commented on the accusation yet. The artist said that he posted his fan art design inspired by Disney's Enchanted Tiki Room to Thingiverse to share his design with people. But a freelance artist who had contract with Disney downloaded this and gave it to Disney to produce the design. He even posted plenty of videos to show the evidences on his Tiktok account, including different tiny details of Disney's toy that were identical to his design [Joris 2022]. In this article's scope, the judgment is unnecessary but the story still provide us with awareness about copyright infringement in AM Industry.

## 3. CURRENT ANTI – COUNTERFEITING METHODS

Anti-counterfeiting methods for AM include methods to keep the uniqueness of the models or products, making it easy for users to differentiate between authentic products and fake ones. These methods can be categorized by the part of the producing-and-selling process that they affect:

1. Methods that affect the production line: methods in this category aim to keep the production line in high security and remove the risk that the process would be copied. For example: using blockchain [Holland 2017], using an internal monitoring system.
2. Methods that affect the products/models: these methods aim to attach additional components to the products in order to make them unique and unable to be copied. For example: adding Fluorescent Substances [Gibson 2010], adding watermarks (digitally or physically) [Peng 2021], [Eisenbarth 2020], [Gao 2021], [Lai 2022].
3. Methods that affect the logistic line: these methods aim to educate customers and clients to check for the authenticity of the products in order not to buy the fake product without value guarantee of the company. For example: using official distributor, limiting the quantity of the sale, etc.

Recently, there are two main methods to implement anti-counterfeiting measures in 3D printing (see Fig. 3). One involves physical techniques, such as incorporating fluorescent substances or labels, but these methods require specialized equipment and can be costly and time-consuming. The other approach involves embedding digital watermarks directly into the 3D model files, but this can be a difficult process and may vary based on the precision of the printer used. However, these methods mainly protect the final printed product and do not address unauthorized tampering with the digital model files. Paying close attention to STL files from the start is vital to ensuring the security of the entire industrial chain.

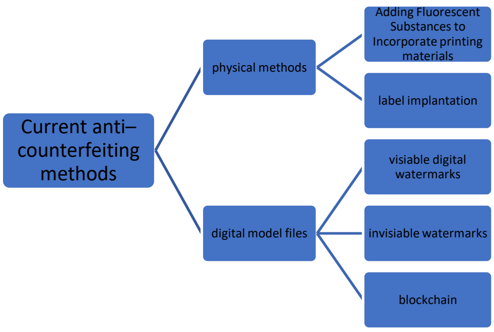


**Figure 3.** Overview anti-counterfeiting methods

Our proposal for improving the protection of digital model files upstream involves the utilization of blockchain technology to verify the authenticity and reliability of STL model printing directly from the source and will be presented in the next session.

### *3.1. Physical Methods*

**Adding Fluorescent Substances to Incorporate printing materials**

This method relied on fluorescence, which can only be used effectively with a chemical additive in the material. The product material has to be photo-resin in order to mix with this chemical additive. With different materials, the manufacturers need to find an unusual way to attach the anti-counterfeiting photo-resin component in order to form a unique product license. The process can be done by different types of light sources including a laser (Stereolithography or SLA), a projector (Digital Light Processing or DLP) or LEDs & Oxygen (continuous digital light processing or CDLP/ continuous liquid interface production or CLIP) [Pagac 2021].

As shown in Fig. 4, this process uses a vat of liquid photopolymer resin to construct the 3D object layer by layer. An ultraviolet (UV) is used to cure or harden the resin where required, whilst the base containing the object will move downward after each finished layer [Gibson 2010].

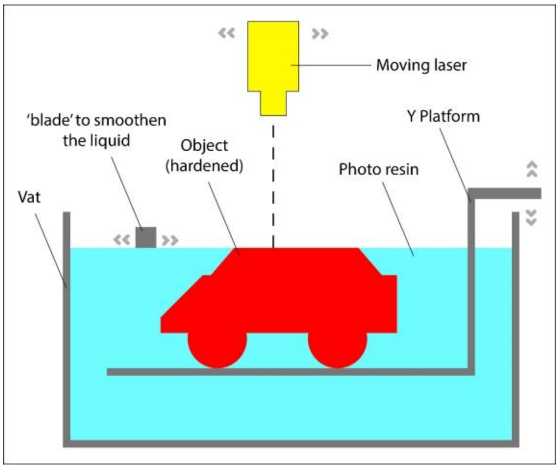


**Figure 4.** Vat photopolymerisation process model [Gibson 2010].

The process of photopolymerisation is described step by step in Fig. 5. When the corporation needs to put anti-counterfeiting components on products, the producer has to mix DCCA into the photo-resin and form a unique pattern, which can be put on the final product. This chemical additive helps add strong fluorescence to the photo-resin product [Qiu 2020], which can be detected by X-ray or ultraviolet devices.

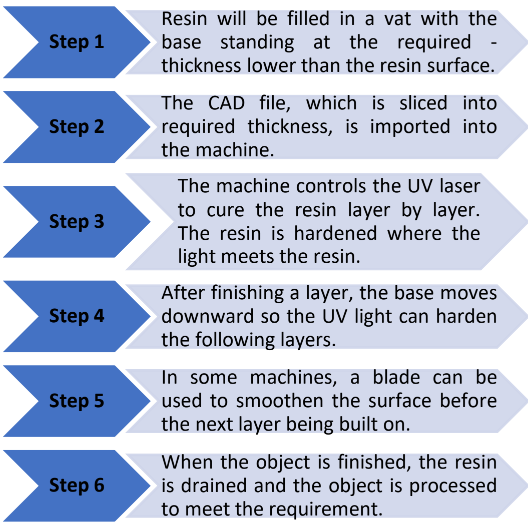


**Figure 5.** Vat photopolymerisation process [Gibson 2010]

**Label Implantation**

This method relied on an internal pattern of the product, which can not be seen from the outside but can be detected only by an eddy current hardware. The product material has to be inspecting electrically conductive [García-Martín 2011] so that the internal pattern (Fig. 6) can be detected with electrical current. With different products and materials, the metallic anti-counterfeiting component can be attached as a badge or logo in order to act as a verification certificate.

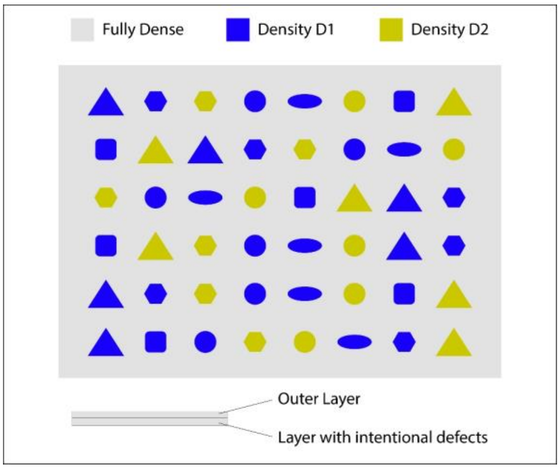


**Figure 6.** The internal pattern created by different density inside the product [Eisenbarth 2020].

This producing process uses the layer-by-layer fabrication to form the pattern by creating intentional defects like poers. After the pattern was formed, the remaining layers would be printed right above and cover the pattern [Eisenbarth 2020]. The process of label implantation is described step by step in Fig. 7.

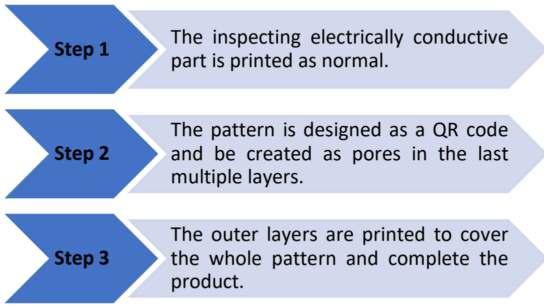


**Figure 7.** Label implantation process [Eisenbarth 2020].

When the corporation needs to put anti-counterfeiting components on products, designers need to create a unique pattern and have it printed under the outer layers. With the help of eddy current hardware, this pattern can be detected as shown in Fig. 8 [Zetec n.d.] and verified by the verifier, who was informed about the pattern before.

### *3.2. Digital Methods*

**Visible Digital Watermarks**

This method relied on an embedding algorithm in order to embed a visible watermark on the model. The watermark can be various from Latin characters, Chinese characters to numbers, patterns and symbols. The embedding process requires a special algorithm and the process to restore the original model also requires a reversible algorithm with the embedding information from the manufacturing firm.

The embedding process can be applied on any 3D data set. After the whole product is designed, an algorithm including the watermarking information (area of the watermark) would find the smooth area of the product, which can be placed inside the interiors or the surface of complex models [Ueng 2021]. Then this smooth area would be divided into several triangles from a single center triangle. The embedding information would include the position of the center triangle, how many times this triangle is divided and etc [Peng 2021].

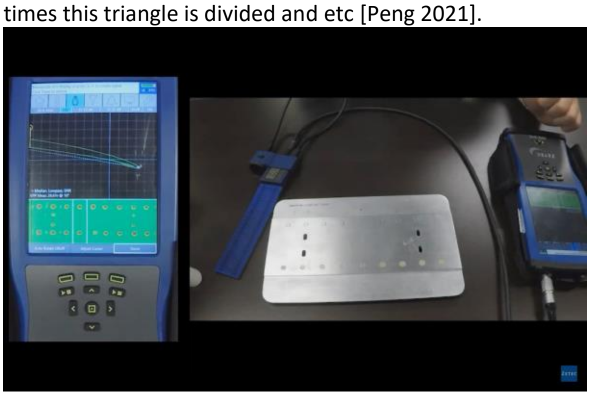

**Figure 8.** A basic view of how internal pattern can be detected by an eddy current hardware [Zetec n.d.].

The process of this method is described step by step in Fig. 8. When the designer wants to send the STL file to the manufacturer, the designer would embed a watermark into the file. Then the designer would send the reversing information (the key) independently to the manufacturer so that they can restore the original model. Without appropriate reversing information, the manufacturer, who wants to restore the original product, would need to find the position of the triangle, the number of times that the triangle is divided by test - error, which takes a lot of time and effort.

**Invisible Watermarks**

This method relied on embedding digital watermark on the STL file to make the file the proof of counterfeiting. This watermark contains different pieces of information generated by the original 3D printer. This information will not affect the product or model design but will stay in the STL file as copyright information. This watermark can not be remodified because each 3D printer has its unique fingerprint, which is relied on to generate the watermark. However, the watermark doesn't affect the printed products, but it can change the wireframe of the product, therefore make the counterfeit be different from the genuine model [Gao 2021].

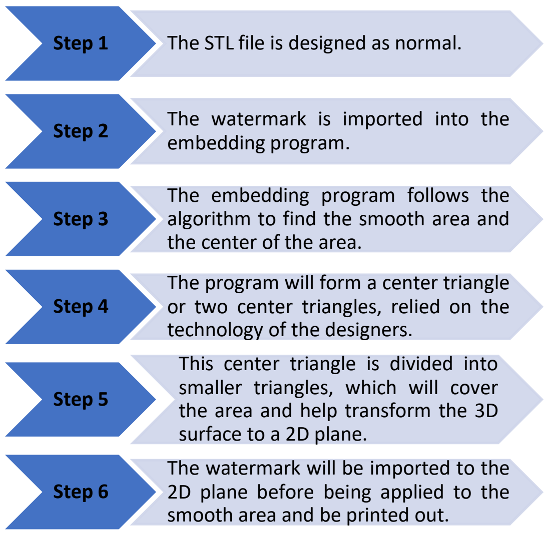


**Figure 9.** Visible Digital Watermark implantation process [Peng 2021].

The watermarking process can be applied to any STL file with the help of different tools and cannot be distingushed between the original model and some random manipulation of the files [Mark 2021]. The model is first designed as normal before it is imported to the tools to be watermarked. These tools have the ability to check for watermark so if there is any watermark, the new watermark can not be overwritten. The process of this method is described step by step in Fig. 10.

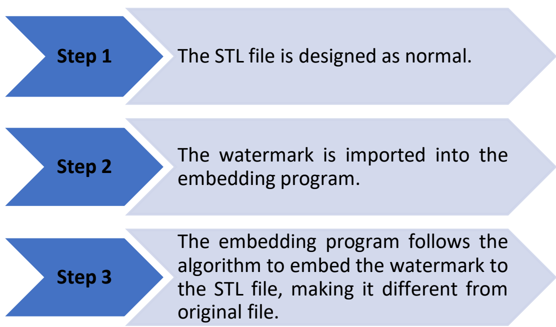


**Figure 10.** Invisible Watermark implantation process [Gao 2021].

After finished designing the products, the designer will have the original data set be watermarked and then can post the watermarked STL file anywhere without the worry about losing the copyright and license of the STL file. The original file can still be sent to the manufacturer who pays to buy the design, but if the firm wants to use the watermarked file, it will not be as functional as the original file, which may cause some severe problem especially for medical tools or equipment.

**Blockchain**

This method relied on blockchain technology. Each STL file transaction will create a Smart Contract with the information about the printing file, the time it can be printed, the fingerprint of the designer, and the fingerprint of the printer. The 3D printer will then verify the license and print the exact number of products in the smart contract. This method allows designers not to completely sell out their design but to sell out permission to print their product [Holland 2017].

This method can be used widely in a variety of products to protect the copyright as well as support supply chain [Kurpjuweit 2021]. The blockchain is illustrated in the form of a trading platform, which helps designers and printers connect to each other.

The process of this method is described step by step in Fig. 11. After the STL file is designed, the designer can upload the design to any platform and start selling the permission to print the design for money. The transaction of the design will be hashed into fingerprints, which will be saved on the blockchain. This will ensure that the transaction is unique and unmodifiable. Without the fingerprint of the transaction, the printer would lack the information and be not able to print out the product.

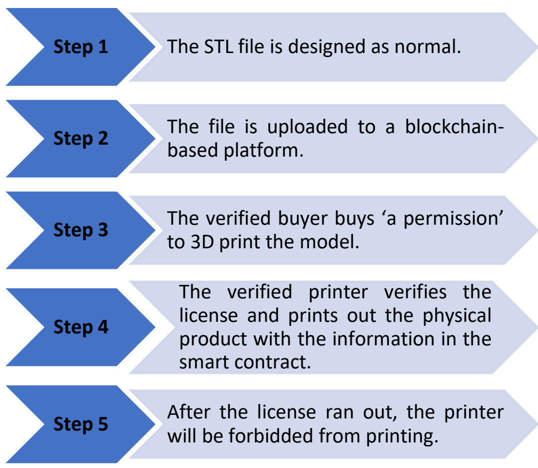


**Figure 11.** Blockchain - based Anti - counterfeiting Process [Holland 2017].

### *3.3. Comparison*

In terms of copyright protection, practical items or works in the public domain are not covered. Libraries may encounter legal issues of copyright infringement either directly or indirectly by providing equipment that could potentially be used to infringe on a copyright. To mitigate this risk, libraries can establish policies governing the use of 3D printers, which may include implementing a mediated service model and considering the "unsupervised copying" exception in copyright law for libraries and archives. Educating patrons on 3D printing presents a chance for libraries to communicate their policies on copyright and usage.

In the five methods mentioned above, the physical methods have direct affect on the physical products in order to create a unique pattern, which then become a proof of license and copyright protection. The watermarking (both visible and invisible) digital methods help protect the STL file from intellectual thieves. The last method using blockchain helps protect the STL file as well as the transaction, creating protection for the whole buying and selling process. The brief comparison between five methods will be listed in the Tab.1

| | **Adding Fluorescent Substances To Printing Materials** | **Label Implantation** | **Visible Digital Watermarks** | **Invisible Watermarks** | **Blockchain** |
|---|---|---|---|---|---|
| **Affected Part** | Physical products | Physical products | STL file | STL file | STL file and transaction |
| **Printing Material** | Photopolymer [Gibson 2010] | Inspecting electrically conductive material [García-Martín 2011] | Any materials | Any materials | Any materials |
| **Verifying Process** | Using ultraviolet devices to find the fluorescent pattern [Qiu 2020] | Using eddy current testing hardware to find the unique defects pattern [García-Martín 2011] [Eisenbarth 2020] | Using visible watermark to claim the ownership of the STL file [Peng 2021] | Using invisible watermark to claim the ownership of the STL file | Using blockchain technology to protect the STL file from unexpected production |
| **Requirements** | Fluorescent subtances with suitable printing method.<br><br>Ultraviolet devices for verification. | Metal printing equipment including printers, washers and sinters.<br><br>Suitable eddy current hardware for verification. | Suitable algorithm to protect the watermark from being removed easily [Ueng 2021] | Suitable tools to embed the watermark into the STL file without changing the quality of the design [Gao 2021] | Blockchain - based platform in order to create and protect the transaction flow of the STL file [Aija 2022].<br><br>Printers and designers need to be verified in order to join the chain of designs [Holland 2017].<br>- Skilled workers to handle the use of blockchain platform [Amend 2021]. |

***Table 1.*** *Comparison of 5 anti - counterfeiting methods.*

## 4. CONCLUSION

In conclusion, the copyright issue is the most important part of AM industry. If this problem is not solved properly, this will severely affect the benefit and revenue of the manufacturers. Moreover, in terms of medical equipment, copyright issue become more severely because medical equipment requires really high standard [International Organization for Standardization 2016]. Without solving copyright issue, additive manufacturing industry will soonly become unprofitable industry without any investment of corporations. In five methods mentioned above, corporations can use multiple different methods on the same products in order to protect the intellectual value. However, for the sustainable and high-pace growth, a blockchain-based platform is required to help develop additive manufacturing industry in terms of quantity as well as quality of designers and manufacturers.

In the future, with the existence of chain of trading designs, each design can have their own value and price. With the current development of cryptocurrency, this industry is able to become profitable and investment-attractive for corporations as well as individual designers or manufacturers.

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