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Advantages of 3D Printing for Circular Economy and Its Influence on Designers

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Abstract

Based on the theoretical research of 3D printing and circular economy, combined with case studies, this paper analyzes the advantages of 3D printing in realizing circular economy and its influence on designers from the perspectives of "reduce", "reuse", "recycle" and distributed manufacturing. As a technological innovation, 3D printing not only promoted the transformation from linear economy to circular economy, but also had a certain impact on the role and skills of traditional designers.

Keywords: 3D printing, circular economy, distributed manufacturing, roles and skills of designers, 3R principle

1. Introduction

With the continuous advancement of global sustainable development strategy, more and more countries and enterprises realize the opportunities brought by circular economy and begin to explore its value potential (Geissdoerfer et al., 2017). In July 2021, China's national development and Reform Commission issued the 14th Five-Year Plan for the development of circular economy. By 2025, the circular production mode will be fully implemented, green design and cleaner production will be widely promoted, the comprehensive utilization capacity of resources will be significantly improved, and the resource circular industrial system will be basically established (National development and reform commission, 2021). In addition, the EU also released a new version of the circular economy action plan in 2020. The core content is to apply the concept of circular economy to the whole life cycle of products, accelerate the change of linear economic development mode, reduce resource consumption and carbon footprint, and increase the utilization rate of recyclable materials (Zhou et al., 2021). Developing circular economy has become a key strategy for countries and enterprises to achieve sustainable economic development and improve international competitiveness.

On the other hand, with the continuous development of digital manufacturing technology, 3D printing began to enter our life. It is a process of establishing a 3D digital model of the object to be printed by using computer-aided design or image technology, then the model data are processed by two-dimensional layering and slicing, and finally stacking materials layer by layer to form a three-dimensional object by computer-controlled 3D printing system (Wegst et al., 2014). Compared with the traditional subtraction and equal processing technology, 3D printing has the advantages of short processing cycle, high resource utilization, not limited by the complexity of parts, energy conservation and emission reduction (Han et al., 2021). As an important symbol of the third industrial revolution, it is highly in line with the global sustainable development strategy. It is widely used in product manufacturing and customized processing, and has achieved remarkable results. In recent years, 3D printing has provided a more sustainable production mode for enterprises with its unique advantages, and has gradually become an important way to realize circular economy (Despeisse et al., 2017). Therefore, exploring the principle of 3D printing promoting circular economy and its impact on designers is a very meaningful research, which can provide a certain reference for the sustainable development of 3D printing.

2. Overview of circular economy

In the past few decades, enterprises have been following the development model of linear economy, extracting resources from nature, processing them into products, and discarding them after use. This single channel material flow model realizes economic growth by continuously turning resources into waste, resulting in the lack of natural resources and environmental pollution. We not only regard the environment as a warehouse of inexhaustible resources and ask for resources arbitrarily, but also regard the environment as a garbage can without capacity limit (Shedroff, 2009). Due to the unsustainability and environmental negativity of the traditional linear economic model, a new economic model has emerged. In the 1960s, American economist Kenneth Ewart Boulding first put forward the thinking of circular economy (Shen et al., 2020). Circular economy, also known as resource circular economy, is the abbreviation of material closed-loop flow economy. It is an economic development model characterized by resource conservation and recycling and coexisting harmoniously with the environment. It transforms the one-way material flow process into a process of repeated circular flow, from resources to products and then to renewable resources, realizing low input of resources, high utilization and low emission of waste, thus reducing the conflict between environment and development (Gao, 2016), as shown in Figure 1.

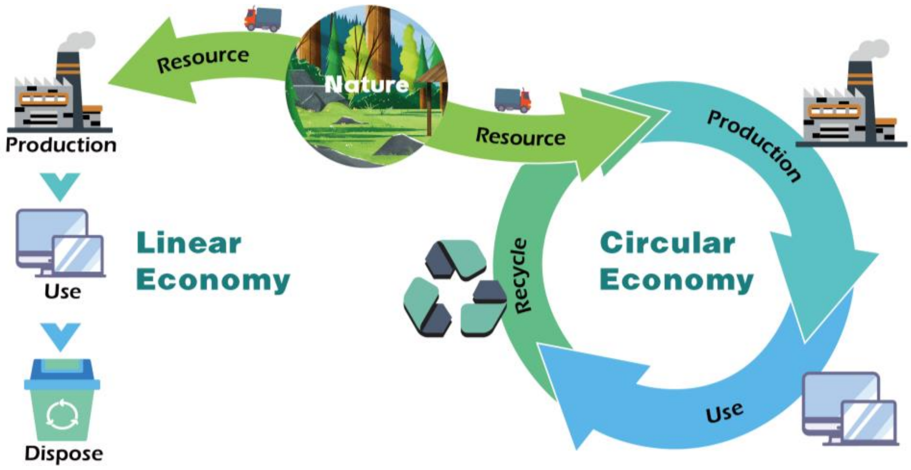

Figure 1. Linear economy and circular economy (Picture was made by the author)

Circular economy mainly follows the 3R principle (reduce, reuse and recycle), and its core is to maintain the permanent utilization of material resources and human sustainable development (Dyer et al., 2021). "Reduce" is the first principle of circular economy. It requires to use as few raw materials and energy as possible in the production process to complete the predetermined production objectives, reduce the consumption of resources and energy at the source, and prevent the generation of waste and pollutants. "Reuse" is the second principle of circular economy. It requires producers to make products durable and reusable as much as possible in the stage of product design and production. Reuse can effectively prolong the service life of products, prevent products from becoming garbage prematurely, and encourage the development of remanufacturing industry to disassemble, repair and assemble used and damaged products. "Recycle" is the third principle of circular economy. It requires that products can be turned into usable resources after being discarded and enter the production process again, so as to reduce the generation of waste and the consumption of natural resources (Luo and Gao, 2015).

With the development and application of circular economy in different fields, its principles have been further improved, from 3R to 6R (Jawahir and Bradley, 2016) or even 10R (Modgil et al., 2021), on the basis of 3R principle, the principles of rethink, repurpose, repair, refurbish and so on are added. However, the 3R principle is still the core and recognized principle of circular economy. Moreover, considering the current characteristics and application of 3D printing technology. Therefore, this paper discusses the advantages of 3D printing in promoting the development of circular economy based on the 3R principle of circular economy.

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3. 3R advantages of 3D Printing

3.1. "Reduce" advantages of 3D printing

“Reduce” is the first principle of circular economy. It belongs to the input terminal and aims to reduce the use of product raw materials and the emission of pollutants (Yuan, 2010). Traditional machining from more to less cutting methods will not only produce a lot of waste and pollutants, but also have low processing efficiency, which is easy to cause unnecessary waste of resources. Compared with the traditional subtraction process, 3D printing as an additive manufacturing process, produces products by stacking melted materials, and can directly produce parts of any shape from computer graphics data without the participation of machining equipment and molds. In the processing process, it will not cause the waste of forming materials, but also be more efficient and effectively reduce carbon emissions (Zhu, 2015).

In addition, 3D printing as a digital manufacturing technology, designers and engineers can optimize relevant algorithms and digital models through computers, so as to improve printing efficiency and reduce the use of raw materials. For parts that do not need stress, designers can reduce the wall thickness of parts or design hollow parts. For products that need to be assembled by dozens or even more parts, 3D printing integrated design can realize the "slimming" of products. On the premise of ensuring the product function, multiple parts can be integrated to directly obtain the overall parts without assembly, which can not only greatly reduce the number of parts and material consumption, but also simplify the manufacturing process and save the assembly cost (Liu and Yuan, 2021). For example, GM (General Motors Corporation) has developed a new car safety belt bracket by combining 3D printing integration technology with generative design. Compared with the old seat bracket, the new seat bracket combines the original eight parts into one part, which is 40% lighter and 20% stronger than the old seat bracket, which not only reduces the weight of the car, improves fuel efficiency, but also improves the performance of the car (Schwab, 2018), as shown in Figure 2.

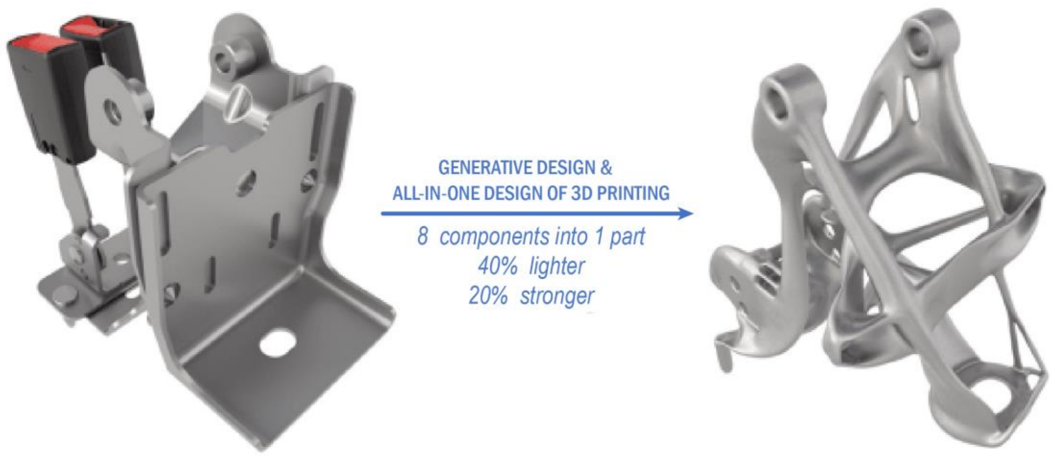

Figure 2. GM Corporation produced car safety belt bracket (Autodesk, 2018)

In addition, for the product shape that needs support materials in the printing process, designers can reduce or avoid the use of support materials by optimizing and adjusting the product shape and structure.

3.2. "Reuse" advantages of 3D printing

“Reuse” is the second principle of circular economy. It belongs to process and aims to prolong the service life of products (Xu, 2014). At present, linear economy encourages people to discard damaged products and continue to buy new products, which is a huge waste of resources, but it also contains many uncontrollable reasons. On the one hand, the production date of some old products is too long to obtain the spare parts required for maintenance. If the traditional mass processing method is used to produce small quantities of old product parts, it will lead to the increase of production cost and part price, and lose the significance of repairing products. On the other hand, for some integrated or simple products, spare parts have not been produced from the beginning of research and development, so when

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these products are damaged, people can only choose to discard them. With the popularization and application of 3D printing technology, people begin to notice its potential in product repair and prolonging product life cycle (Ford et al., 2015). At present, 3D printing can be combined with 3D scanning and 3D modeling to repair damaged product parts, so as to prolong the service life of products and avoid discarding behavior. For example, the "value added repair" project developed by Conny Bakker and Marcel den Hollander of Delft University of technology in the Netherlands aims to use 3D printing technology to repair damaged products and add value to them. As shown in Figure 3, repairing the damaged tea set through 3D printing can not only make the tea set look new, but also make the repaired tea set more humanized. Like this cup with a damaged handle, the 3D printed parts not only repair the damaged handle of the cup, but also ensure that people will not burn their hands when drinking hot drinks with this cup (van Dijck, 2020). In addition, 3D printing can also print directly on the surface of some products, such as printing missing parts directly on damaged product parts, which will further save raw materials and energy (Matsumoto et al., 2016).

Figure 3. 3D printing repaired the damaged tea set (Photo by Marcel den Hollander)

3D printing can not only repair damaged products, but also improve the use value of waste products. For example, Samuel Bernier takes 3D printing as a DIY tool to promote product reuse, creates customizable covers by using low-cost 3D printing, and converts used bottles and cans into new daily necessities, such as watering can, hourglass and noodle container (Bernier, 2012), as shown in Figure 4. The project is open source. People can download and print files online, and then adjust the size, color or shape according to their own needs, so as to better transform the bottles and cans around them. The designer transforms the bottles and cans originally discarded as waste into new products with use value, which effectively prevented the generation of waste and environmental pollution.

Figure 4. Use 3D printing to convert discarded bottles and cans into daily products (Picture from: https://www.instructables.com/Project-RE-by-Samuel-Bernier/)

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3.3. "Recycle" advantages of 3D printing

"Recycle" is the third principle of circular economy. It belongs to the output terminal and aims to recycle waste again to reduce the final use (Yan, 2019). At present, 3D printing materials are developing in a sustainable direction. New printing consumables are made by recycling printing products, plastic parts, mineral water bottles and other wastes, so as to reconvert the wastes into raw materials and continue to produce products. The new raw is a design studio in Rotterdam, the Netherlands, it launched a plan called "printing your city", which aims to use 3D printing technology to close the loop of plastic waste flows, so as to better recycle plastic waste in the city and print them into public furniture. This bench is called "XXX bench", which is printed from recycled plastic waste. It weighs 50kg, is 150cm long and 80cm wide, and can accommodate two to four people. It takes the form of a double-sided rocking chair, which is designed to act as a statement on working together to close the loop of plastic. Users have to find equilibrium together or use their energy to rock each other (Rinaldi, 2017) as shown in Figure 5. The shape and size of this bench can be customized to meet specific needs, and enterprises can also integrate logo or information into the design. At the end of its service life, it can be 100% recycled, and it is composed of a single material. Compared with the bench composed of different materials, it can effectively avoid the energy consumption of material separation and is more conducive to later recycling (Sauerwein et al., 2019).

Figure 5. XXX bench (Picture from: https://thenewraw.org/Print-Your-City-Amsterdam)

In addition, 3D printing can also use recyclable biomaterials as printing consumables to avoid waste in the later stage directly from the source of product production. For example, the common PLA material in 3D printing industry is a new type of bio based and renewable biodegradable material, which is made of starch raw materials extracted from renewable plant resources (such as corn, cassava, etc.). It has good biodegradability and can be completely degraded by natural microorganisms under specific conditions to produce carbon dioxide and water, so as to realize the circulation in the natural system. Moreover, PLA as a 3D printing material, it also has the characteristics of smooth surface, good flexibility at room temperature, good fluidity, small shrinkage and excellent mechanical properties (Rui, 2021). For example, as shown in Figure 6, the food industry prototype printed with PLA material. When its life cycle ends, this material can not only enter the natural environment to provide nutrients for other organisms, but also enter the industrial cycle system to become a new material or product again.

Figure 6. Food industry prototype printed using PLA materials (Picture from: https://www.hubs.com/knowledge-base/pla-vs-abs-whats-difference/)

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4. Distributed manufacturing advantages of 3D printing

Under the background that the global economy is generally facing weak growth and huge environmental pressure, the economic development model has gradually changed from centralized to decentralized and distributed (Baran, 1964), as shown in Figure 7. The concept of distributed economy first appeared in the early 20th century. Scholars Johansson and others defined it as small-scale regional production units, which cooperate with each other and make use of local resources (Johansson et al., 2005). According to the different resources shared by production units, the International Learning Network on Sustainability divides the distributed economy into seven categories: distributed manufacturing, distributed food production, distributed water management, distributed energy generation, distributed software development, distributed information and distributed design (Xia et al., 2018). Distributed manufacturing means that manufacturers with different production scales and in different regions establish cooperative relations to provide products or services that can quickly respond to market demand (Meng and Guo, 2017). As a small, flexible and easily accessible processing method, 3D printing is easy to realize distributed manufacturing, and the concept of distributed manufacturing can solve the problems of low resource utilization and unsustainability caused by the uneven distribution of 3D printing equipment (Greenfield, 2017).

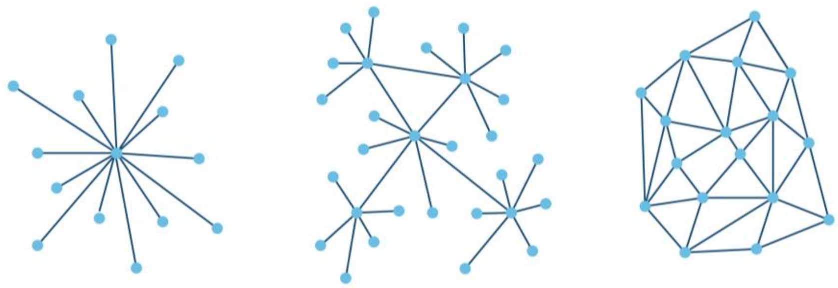

Figure 7. Diagram of centralized, decentralized and distributed economic models (Picture was made by the author)

For example, 3D Hubs, an online 3D printing service platform in Amsterdam, the Netherlands, is a typical distributed manufacturing model. 3D Hubs is mainly committed to providing a platform to connect users with 3D printers with users who need 3D printing services, and encourage 3D printer owners to provide 3D printing services and technical support to nearby users. Users all over the world can upload design documents online using 3D Hubs platform to obtain quotations. The platform will automatically assign orders to the local supplier closest to the user, and then the local supplier will provide users with efficient 3D printing services, and finally deliver the products to users, as shown in Figure 8. The distributed manufacturing system of 3D printing is smaller in scale, and the structural relationship of each production unit is more equal. When dealing with external demand, the system is not only more flexible, but also more active in response. Compared with centralized manufacturing system, the production unit of distributed manufacturing system is closer to users, which can encourage users to actively participate and develop customized solutions.

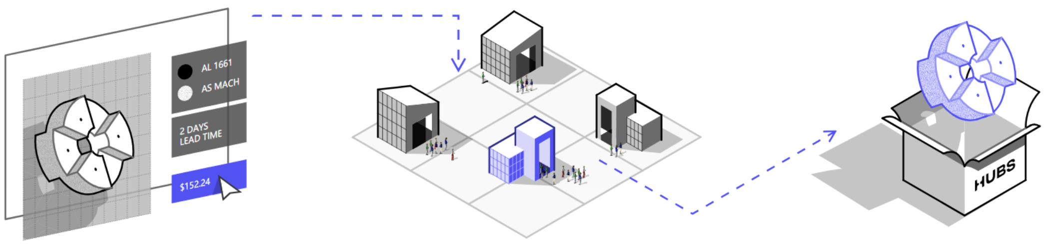

Figure 8. Operation mode of 3D Hubs (Picture from: https://www.hubs.com/)

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Imagine that if there are 3D printing manufacturing points in the convenience service center of the community or nearby stores, users do not need to place orders online or wait for logistics. They can directly use the 3D printers of distributed manufacturing points to print products. This not only saves the energy loss caused by warehousing and logistics, but also promotes more people to use this technology, which is conducive to promoting the development of circular economy.

5. The influences of 3D printing on designers

In the process of promoting the development of circular economy, 3D printing also has a certain impact on the role and ability of traditional designers.

First of all, the "reduce" advantage of 3D printing requires designers to master the technical specifications, working principle and use process of 3D printing. Only in this way, the designer can optimize the printing method and reduce the amount of material and pollutant emission by adjusting the product shape or structure during the design stage, thus realizing the green design of the product. In addition, 3D printing integrated design not only requires designers to break through the thinking limitations of traditional casting, injection molding and machining processes, but also requires designers to master relevant design methods and software. For example, fusion 360 software developed by Autodesk company can provide generative design for manufacturing industry. It can use artificial intelligence technology to quickly generate multiple design alternatives according to process, material, cost and other parameter constraints, and designers can choose the best solution according to technical requirements (Zhang, 2016). The application of generative design in the field of 3D printing integrated design can effectively improve the efficiency and quality of designers to optimize complex products or parts, so as to speed up the product development process.

Secondly, the "reuse" advantage of 3D printing requires designers to master reverse engineering technology and its related engineering equipment and software. Reverse engineering refers to the process of transforming the physical model of a product into a three-dimensional digital model through three-dimensional measurement technology or sensor equipment (Shen, 2018). It mainly includes three steps: geometric measurement, data processing and digital modelling (Chen and Zhong, 2020). In traditional engineering production, product design generally adopts forward engineering design. Firstly, the product design solution is put forward through preliminary research, then the three-dimensional modeling of the design solution is carried out through computer software, and finally it is processed and formed through processing technology (Zhang and Yu, 2016). However, for damaged or abandoned products, it is difficult for designers to obtain the technical drawings of such products due to the long production time or the protection of intellectual property rights of enterprises. In this case, the designer must use the thinking and method of reverse engineering to measure and analyze the damaged product, so as to obtain the digital model of the product, then design the part model suitable for it based on the three-dimensional model of the product, and finally produce it through 3D printing.

Finally, the "recycle" advantage of 3D printing requires designers to master some knowledge and skills in the field of materials and biological design. Because the "recycle" advantage of 3D printing is mainly reflected in the reuse of existing waste and the recyclability of new printing materials. Designers should have a certain understanding of the material types, characteristics and processing methods of different wastes, and can identify which waste materials can be transformed into consumables for 3D printing, as well as which products these waste materials are suitable for production through 3D printing. In addition, designers should also understand some basic knowledge of biomaterial design through literature research and other methods, and can try to use animal and plant raw materials or organic waste in life to design biomaterials suitable for 3D printing, so as to promote the sustainable development of 3D printing products.

On the other hand, the distributed manufacturing advantage of 3D printing promotes the rise of social design and puts forward higher requirements for designers' soft skills. Previously, due to the manufacturer's monopoly on the product production stage, the product design and development were basically dominated by the enterprise, the specific process was implemented by the designer, and the user can only passively accept the results (Zhang and Li, 2013). With the rise of digital manufacturing technology, the manufacturing mode of products began to shift from centralized and mass professional manufacturing to distributed and small batch social manufacturing. More and more people began to

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contact 3D printing and use this technology. In this post-industrial era, everyone can become a designer and manufacturer. Traditional designers no longer rely on their own strength to complete the design independently, but begin to play the role of design organizer or promoter, and adopt the method of collaborative design to jointly promote the design project with users (Wang, 2012). However, in the process of collaborative design, most users do not have professional knowledge in product modeling, 3D printing and design. In this case, users need the assistance of designers to express and realize their design ideas, which requires designers not only to master basic professional hard skills, but also to improve their collaborative design ability, interpersonal communication ability, communication and organization ability and a series of soft skills (Ritter et al., 2018). Only in this way, designers can better cooperate with users. Even if users do not have professional knowledge in the design field, as long as they have the creativity of product design, they can communicate with designers in time to design the desired products and realize them through 3D printers.

Secondly, the distributed advantage of 3D printing has also promoted the rise of independent designers and design brands. The traditional centralized and mass production mode mainly reduces the cost of a single product by increasing the number of products. If designers want to produce small quantities of products independently, they need to pay expensive production costs to manufacturers, which will lead to the rise of the price of final goods, which is not conducive to the promotion and sales of products. Therefore, if designers want to turn their ideas into practical and marketable products, they must cooperate with manufacturers or directly join enterprises as enterprise designers. Moreover, in this case, in order to ensure the quality of products and design expectations, designers need to go back and forth to the factory many times to communicate with engineers, which is a waste of time and energy. Compared with traditional processing technology, 3D printing can directly help designers manufacture small quantities of design works locally, which not only relieves the limits of traditional processing technology and manufacturers on designers, but also reduces the distance between designers and processing, which is conducive to designers to create and promote their own studios and brands.

6. Conclusions

Circular economy is the fundamental way to solve the contradiction between economic development and ecological environment, and it is also a necessary measure to realize sustainable development (Hu and Gao, 2011). With its advantages in “reduce”, “reuse”, “recycle” and distributed manufacturing, 3D printing has promoted the transformation from linear economy to circular economy. Its “reduce” advantage reduces the use of raw materials and pollutant emissions from the input end. Its “reuse” advantage effectively prolongs the life cycle of waste products and reduces the consumption of resources and energy to a certain extent. Its "recycle" advantage can not only put some waste of the linear economy into production again, but also directly use recyclable biological materials to realize the recycling of resources and avoid the generation of waste. The advantage of distributed manufacturing effectively shortens the distance between users and production, not only reduces transportation costs and carbon emissions, but also helps to promote 3D printing technology and customized design.

As a technological innovation, 3D printing has promoted the role transformation of traditional designers to design engineers, design organizers and independent designers in the process of realizing circular economy. In order to better use 3D printing in the design process, designers not only need to master professional skills in the field of design, but also need to master some knowledge and skills in related disciplines and engineering fields. In addition, in the process of collaborative design, designers also need to improve their soft skills to better communicate and cooperate with users and jointly promote the development of the design process.

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