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Overview of Industry 4.0 Specific Application Scenarios

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Abstract

After the concept of Industry 4.0 was put forward, with the development of social economy, China has entered the era of Industry 4.0, in this context, the development of cross-enterprise and cross-sector will form a trend. This has prompted the field of automotive industry to enter the intelligent development stage, and in the intelligent development stage, the application of industrial design in which plays an important role in promoting. For this reason, by studying the application of intelligent manufacturing in industry 4.0, the research analyses the application of industry 4.0 in various fields.

Keywords

Smart Manufacturing, Industry 4.0, Application Scenarios.

1. BACKGROUND OF THE STUDY

"Industry 4.0" is one of the ten future projects identified in Germany's 2013 High Technology Strategy 2020, which aims to support the research and development and innovation of a new generation of revolutionary new technologies in the industrial field, and to promote the transformation of manufacturing to intelligence. German Chancellor Angela Merkel pointed out that the future of intelligent factories will be able to run on their own, machines and components can communicate on their own, which promotes the cooperation of various industries. German academia and industry believe that, following the steam era, the electrical revolution and the information revolution, mankind will step into the fourth industrial revolution based on information-physical systems, marked by a high degree of digitalisation of production, networking and self-organisation of machines, and dominated by intelligent manufacturing[1].

With the development and progress of the times, China's comprehensive national power is also increasing. General Secretary Xi Jinping, in his important speech at the opening ceremony of the 19th Academician Conference of the Chinese Academy of Sciences and the 14th Academician Conference of the Chinese Academy of Engineering, emphasised the importance of aiming at the world's scientific and technological frontiers, leading the direction of scientific and technological development, seizing the early opportunities and rising to the challenge, and building the world's scientific and technological power. It can be seen that the development of science and technology plays an increasingly important role in improving the comprehensive national power, promoting the prosperity of the country and progress in various fields. Although China has written a manufacturing saga in the last 30 years, its productivity is still lagging behind that of developed countries, only 1/5 of that of the dominant developed countries. the rapid development of China's manufacturing industry over the past 15 years has relied mainly on cheap labour, capital and imitation of innovations, which are now being lost. The Chinese government has taken this opportunity to announce Made in China 2025, which seeks to leverage the wave of Industry 4.0 to move from being the world's number one

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manufacturing power to being one of the developed manufacturing powers. This policy is a medium to long term development strategy for the country's industry, focusing on digital, networked and intelligent manufacturing through the deep integration of information technology and manufacturing technology, promoting the transformation and upgrading of the manufacturing industry, the development of modern manufacturing services, and the construction of smart factories/digital workshops in key areas.

In 2014, China and Germany signed the Programme of Action for Sino-German Cooperation, heralding the start of a new round of industrial cooperation between China and Germany. Due to the different industrial environments of the two countries, China and Germany have strong complementarities in traditional industrial co-operation, and China has also taken the opportunity to rapidly enhance its traditional industrial level[2]. At the same time in some new industries, high-end industry, China and the world industrial gap has been minimised, China and Germany in the new industrial cooperation is conducive to common progress. Sino-German industrial co-operation will usher in a new wave of industrial revolution, and endeavour to develop industry and work hard to achieve the desired goals.

2. APPLICATION OF INTELLIGENT MANUFACTURING IN THE CONTEXT OF INDUSTRY 4.0

2.1. Application on the production floor

2.1.1 Automotive production workshops

A well-known domestic automobile manufacturer has carefully built a smart factory, which is strictly planned, designed and constructed in accordance with Industry 4.0 and smart manufacturing standards, introducing numerous intelligent elements and achieving a high degree of automation and digitalisation. Phoenix Contact, as a professional automation system provider with nearly a hundred years of technical knowledge and a wealth of experience accumulated over time in the automotive industry, as well as a deep understanding of Industry 4.0, advised on the design and construction of this smart factory and provided complete solutions, which were comprehensively applied to the welding, painting and final assembly workshops. With PLC and software libraries to help customers tailored to the electrical standards of automotive manufacturing, to help customers establish a fully automated platform, making the project high-quality completion, minimising investment and operating costs.

The welding workshop is planned to be a four-vehicle flexible line, with an automation rate of 85%, 250 robots, medium frequency adaptive welding machines and Nimak welding pliers. The welding workshop requires non-stop welding of different types of car bodies without affecting the production cycle. The fast production pace and high-speed processing of the controller ensure accurate and smooth information flow, which effectively improves the production efficiency and product quality. The process sections in the welding shop include sidewalls, longitudinal beams, front and rear floor panels, nacelles, lower lines, main lines, four doors, and the conveyor system includes sidewall conveyor and WBS (body-in-white conveyor), of which 23 sets of REC470SPN3TX controllers have been used in the system integration, which are used for the control of 228 welding robots, 200 I/O sub-stations of IP20, more than 800 sets of IP67 devices, 179 sets of inverters and 139 sets of SMCs. frequency converters and 139 SMC valve islands[3].

The painting workshop adopts the world's leading water-based paint B1B2 process, the varnish adopts the industry's high-quality 2K system, 42 spraying robots and ostrich feather wiping machines are applied, and the opening and closing of the doors are also controlled by robots, so that the spraying line has achieved 100 per cent automation. During the painting process, a variety of materials are used under different environmental conditions. The

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prerequisite for ensuring the quality of the coating materials is the transparency of the material data and the flexibility of industrial communication technology. The plant's paint shop is divided into the machine and transport area, the process equipment and the paint line, with CAC Engineering being responsible for the total integration.

The assembly workshop has more than 100 "ground-flying" logistics AGVs, which, together with the automated conveyor lines, enable the automatic distribution of 90% of the hungry materials. Among them, 16 sets of AXC3050 controllers are used to control the lifting equipment and conveying system, which has a very fast processing speed and is suitable for medium and large controller system processing tasks.

2.1.2 Intelligent factory for printing and dyeing

Intelligent printing and dyeing enterprises in the automatic distribution of dyes by many enterprises, and by many companies are in the research and development, such as Hangzhou open source, Vantan company and Germany SADO company, they are successfully used in production practice. The establishment of digital monitoring system for printing and dyeing equipment has become the direction of new development projects. The system through a variety of sensors on the production site process parameters such as: water, electricity, steam, temperature, humidity, chemical content, fabric width, quality per unit area, speed and other real-time monitoring, can achieve energy saving and emission reduction, quality tracking, product quality enhancement, improve production efficiency, reduce the use of labour, improve the level of process technology and management level, change the previous operator to rely on the experience of the production, the phenomenon of constraints. Phenomenon. New projects such as Shandong Ruyi Jinxiang Printing and Dyeing Industrial Park, Zhejiang Jinshuo Printing and Dyeing Project; similarly, there are Yixing Leqi, Pleasure Home Textiles, such as well-known enterprises early in the workshop equipment installed a variety of sensors, cost accounting, consumption assessment, to improve the energy-saving emission reduction management level. But there are systems for various process parameters collected to the central control system and the corresponding control is not perfect.

Based on the workshop field operation level of information technology collection system SFC has been gradually attached importance to the production management MES system is also gradually applied to the printing and dyeing enterprises. Improve the basic information in the ERP system and the production process and the enterprise plan of the information gap problem, but also need to fundamentally improve the use of ERP system level[4]. In terms of products, the real intelligent interconnection between materials, production processes and production equipment is the Campina Cylinder Yarn Project. However, there is a fundamental difference between the dyeing of cotton yarn and the dyeing and finishing of cloth from the process to the product form. No company has yet been able to achieve fully intelligent production of cloth dyeing and finishing or, more precisely, continuous printing and dyeing plants for cotton flat fabrics. Rongsheng Dyeing and Finishing is known as a case of successful transformation of traditional printing and dyeing factories into intelligent factories, which is a good benchmark and example for the industry in the direction of intelligent production; however, the company's products are mainly made of chemical fibre and knitted fabric, the dyeing and finishing equipment is basically a single machine cylinder, and the form of fabrics is rope processing, and the interconnection between the cloth transfer equipment is still basically the traditional manual way, which still needs to be improved. Printing and dyeing factories to achieve the purpose of intelligence, including the reduction of labour costs, improve production efficiency, enterprise technology management level, energy saving and emission reduction level, product quality and stability, improve market responsiveness and service capabilities[4].

Embryo cloth transported from the textile factory to the printing and dyeing enterprises from the unloading, warehousing, is the beginning of intelligent production, cloth from the unloading

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of the beginning and the combination of intelligent warehouses, according to the order and the corresponding production process, the MES system automatically matches the corresponding dyes and equipment interconnection. Preparation of embryonic cloth, embryonic cloth into the factory → unloading → warehousing → unpacking → turning → sewing head. Finished product packaging from inspection → cutting → packaging → warehouse → shipping. The printing and dyeing factory is divided into five workshops according to the process, the workshop for storage of blankets, the workshop for pre-treatment, the workshop for dyeing and printing, the workshop for finishing, and the workshop for storage of finished products. Considering the flexible deployment of production, there is an intelligent cloth storage warehouse between the workshops, as a flexible connection of the production process, through the realisation of intelligent production in each workshop, so as to achieve the intelligent production of the whole process.

2.2. Applications in logistics

2.2.1 Intelligent Logistics Technology Requirements

The technical architecture of smart logistics follows the three-layer technical architecture of the Internet of Things, and refines each layer according to the application requirements of modern logistics to provide more effective technical support for modern logistics. The process can be divided into five steps: the first step, consider the basic information of the object to achieve real-time sharing and interoperability; the second step, consider the information of each logistics activity for perception, the integration of logistics information with the information of the object, to ensure that the logistics process of the object is informatised; the third step, the use of automation technology to achieve the automation of the handling process of the object to reduce the intensity of the logistics handling and to improve the accuracy of the logistics; the fourth step, the logistics activities using information technology to link up, to provide more effective technological support for the modern logistics. The fourth step is to link the logistics activities using information technology to achieve the integration and integration of information in the whole logistics process; the last step is to conduct in-depth analysis of each logistics activity, using Internet technology to optimise logistics, and ultimately achieve intelligent logistics.

There are three main layers in the Internet of Things architecture, namely the sensing layer, the communication layer and the application layer.Perception layer is the foundation of the Internet of things, is the interface between the physical world and the information world, is the Internet of things to identify the object, the source of the collection of information; communication layer is mainly to achieve the transmission of information and communication, is responsible for transferring and processing the information obtained by the perception layer; application layer refers to a variety of specific applications for the provision of public services to support the environment is the realisation of the objects and people to identify each other with the perception, play a role in the wisdom of the platform.

2.2.2 Application reality

The first is the choice of supply chain logistics warehousing address, in accordance with the manufacturer, the supplier's geographical location, the actual operating costs, warehouse construction and other elements, to take big data to carry out a comprehensive analysis, to avoid the impact of subjective factors such as the natural environment, to improve the accuracy and reasonableness of the choice of logistics warehousing address, to reduce the cost and improve the efficiency of the supply chain logistics.

Secondly, in terms of materials management, abandon the previous artificial management, replaced by artificial intelligence management mode, the application of big data, Internet of Things, information technology, such as rapid access to storage data information, and all the

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information uploaded in real time under the role of the network and share, reduce the amount of inventory and warehousing costs to ensure that inventory management is more secure. After the realisation of intelligent warehousing, cargo storage management gradually has the characteristics of containerisation and automation. Cargo storage and transport assembly application of artificial intelligence technology, all the goods can use the pallet to achieve point-to-point transport.

Reducing intermediate processes in the transport process also improves the material turnover rate. In terms of warehouse automation and intelligence, an intelligent warehouse is created, and the operation process is changed to automated mechanical equipment, realising automatic sorting of goods, intelligent depalletising and intelligent safety inspection. The application of intelligent algorithms, all automated equipment in the warehouse can coordinate and cooperate with each other, according to the actual situation to carry out operations, and effectively improve the efficiency of warehousing operations. In Industry 4.0, will achieve the true meaning of personalised product customisation, which also requires companies from customer demand, order management, raw material procurement, semi-finished products and product production throughout the process of identifiable, traceable, so the need to use Internet of Things technology to access the system to the computer network, through the RFID technology and GIS technology to complete the number of items, location, the responsibility for the digital personnel information Management[5]. Mainly: identification and positioning of different items in the warehouse, workshop, finished goods warehouse, etc. between the flow, in order to meet the needs of enterprise management; semi-finished products, finished products, the number of automatic statistics and tracking, the information will be transmitted to the order management system, order management system on the order of real-time updates and progress management; through the Internet of Things on the number of raw materials consumed automatic statistics, in order to carry out the logistics of the enterprise's intelligent management.

The next step is logistics transport, transport routes apply artificial intelligence technology, mainly by adopting path optimization algorithms and scheduling algorithms, optimizing the best transport paths according to the information provided by the data centre, and strengthening the rationality of transport routes. Create a real-time database, through the intelligent data analysis platform can optimise the best transport route, improve operational efficiency. Once problems occur during transport, solutions can also be automatically analysed and proposed. Adoption of distribution equipment, generally based on intelligent logistics unmanned distribution vehicles as well as unmanned distribution equipment.

Finally, logistics data traceability, the application of Internet of Things technology can be realised in the supply chain intelligent traceability, from the beginning of the production process until the after-sales process can be achieved to ensure that the information flow, the flow of goods to be unified, and the construction of a complete chain of information, to understand the source of the transport items, the final direction of the distribution as well as the transport link responsible for people and so on. All the complete information chain can constitute an information network, from which to obtain the historical data required by the supply chain logistics, when problems occur in the logistics and transport process, the use of intelligent traceability function to quickly determine the cause of the problem and docking the directly responsible person, the problem will be solved, thus improving the efficiency of the supply chain logistics to ensure the safety of logistics and transport of all aspects of the logistics supply chain, but also provide customers with a more complete logistics supply chain as a guarantee for the future of the intelligent logistics information traceability realisation and innovation. Lay the foundation for the realisation and innovation of intelligent logistics information tracing in the future[6].

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202312_9(12).0011

2.2.3 Development of Intelligent Logistics

On the current point of view, China's logistics industry still has more room for improvement, the following is the future development prospects of intelligent logistics.

China's road transport is currently the problem of high labour costs, the seriousness of the phenomenon of empty loads, the high frequency of accidents and emissions pollution and so on. In this regard, the introduction of self-driving freight line has become a major development direction of China's intelligent logistics. This special line adopts self-driving truck queue technology, construction of road infrastructure, and the use of automatic docking and unloading technology in the terminal, can be a good way to achieve the unified scheduling of vehicles, reduce human labour and transport costs, reduce the rate of empty loads. At the same time, it improves road safety, reduces the frequency of accidents, and creates an unmanned, vehicle-road synergistic and highly intelligent self-driving transport network.

While "carbon peak, carbon neutral" has become the macro background of China's development strategy, the State Council issued a guideline in 2021, making it clear that it is necessary to build green logistics and improve the circulation system of green, low-carbon and recycling development[7]. In order to achieve the dual-carbon goal, the system needs to be in the overall layout, platform construction, facilities supporting, operation and maintenance of emerging technologies in the depth of energy consumption, so as to achieve green and sustainable development. On the basis of the Internet of Things , the creation of a low-power green IoT is the basis for establishing green logistics through the research and development of low-power chips and the optimisation of communication technology algorithms. In addition, it is also required to achieve low-carbon emission reduction in a series of links such as production, packaging, transport, distribution, etc., to create a complete green eco-logistics cycle.

The interconnection of information and data is also an important part of intelligent logistics. At present, enterprises in China still lack digital management tools and processes, and therefore need to promote the construction of a platform for the sovereign exchange of logistics data. At the level of information flow, relying on the advanced nature of China's communication infrastructure, with the credible data exchange platform as the basis, the establishment of a data trading market and mechanism, the protection of enterprise data sovereignty, and the creation of a data ecology of the entire supply chain and value chain. In this way, it helps enterprises to achieve the refinement and credibility of data collection, helps the industry to establish active and secure data management means, and gives full play to data sharing and data mining capabilities to achieve data-driven operation analysis.

2.3. Applications in 3D printing

2.3.1 Current status of 3D printing research

3D printing, also known as additive manufacturing, is an emerging manufacturing technology based on three-dimensional model data to manufacture parts or physical objects by means of material stacking, which will have a far-reaching impact on the traditional process, production line, factory model, and industrial chain combination. That is, from the physical prototype → digital physical three-dimensional prototype → three-dimensional prototype modelling → three-dimensional model of innovative design → innovative physical process[8].

2.3.2 Application scenarios

3D printing is increasingly being used in fields such as machine building, biomedical, and construction.

(1) 3D printing of concrete buildings

China's construction industry is still dominated by the traditional wet work construction mode, 3D printing for the construction industry to achieve industrialisation to provide the

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technical basis, the Ministry of Housing and Urban-Rural Development in 2016 issued the 2016-2020 Development Outline of Information Technology in the Construction Industry, which clearly points out to speed up the research of 3D printing equipment and materials, and greatly promotes the application of 3D printing technology in the field of construction engineering. The application of 3D printing technology in the field of construction engineering, effectively improve the efficiency of the modernisation of the construction industry, and push the construction industry from manufacturing to smart manufacturing. At home and abroad in recent years, there have been colleges and enterprises using concrete 3D printing technology to complete the construction, but most of them are demonstrative cases, and have not yet formed a large-scale printing construction.

Beijing Huashang Luhai Technology Co., LTD used 45d time to print the 1st reinforced concrete villa by 3D printer in Tongzhou, Beijing in 2016, as shown in Figure 1; Eindhoven University of Technology in the Netherlands completed the 3D printed bridge in October 2017, the bridge is divided into 8 sections longitudinally, using a special cement printer to print well in the factory, using pre-stressing tension to form a whole, and transported to the site for the overall lifting; ; Shanghai Construction Engineering Group completed the 3D printing bridge in Taopu Zhichuang City in 2018, the bridge was constructed using a gantry composite 3D printing robotic system in the digital 3D construction centre of Shanghai Construction Engineering Mechanical Engineering Group, with a millimetre printing accuracy, and one-time shaping was only used for 35d, as shown in Figure 2; Ma Guowei's team of Hebei University of Technology was built in October 2019 in Tianjin in accordance with the Zhaozhou Bridge 1:2 scaled-down printing, on-site assembly assembly into a 3D printed bridge, the bridge is currently the world's longest span of assembly concrete 3D printed bridge, is also the world's longest single-span concrete 3D printed bridge, as shown in Figure 3; Southeast University, Hong Kong Wang et al. using architectural 3D printing technology to build a concrete public health control square module in the short time in the Jiangbei New District of Nanjing[9].

Figure 1. 1st reinforced concrete villa by 3D printer in Tongzhou, Beijing in 2016

Figure 2. Shanghai Construction Engineering Group completed the 3D printing bridge in Taopu Zhichuang City in 2018

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Figure 3. Ma Guowei's team of Hebei University of Technology was built in October 2019 in Tianjin in accordance with the Zhaozhou Bridge 1:2 scaled-down printing

(2) Metal 3D printing

The main value of metal 3D printing lies in the application, the current metal 3D printing process technology can manufacture traditional processes are not easy to complete the complex structure of parts and components, to achieve functional integration, lightweight, topology optimization and other advantages, low cost, short cycle time, do not need to open the mold, the ability to print the material including stainless steel, nickel-based alloys, aluminium alloys, and other materials, aluminium alloy AlSi10Mg and stainless steel Aluminium alloy AlSi10Mg and stainless steel 316L are currently the automotive industry in the application of the most 2 materials, has been printed and applied to more examples of metal 3D printing, more representative parts are as follows[10].

Engine cover material for AlSi10Mg, size 410 mm × 320 mm × 190 mm, conventional manufacturing process for casting, high cost, production cycle takes 3 months: the use of metal 3D printing process low cost, short production cycle; manufacturing accuracy and mechanical properties of the parts is better than the casting process; cover blanks trial period from 3 months to 0.5 months, trial period savings of 83%; blank mechanical properties better than casting blanks, blank dimensional accuracy of casting CT7 level, densification of 99.7%; cover blank printing time of 216 h, raw material needs 15 h, the hood blank printing time is 216 h. Cycle savings of 83%; blank mechanical properties are better than casting blanks, blank dimensional accuracy of casting CT7 level, densification of 99.7%; cover blank printing time of 216 h, raw materials need 15.7 kg, the total cost of printing 115,000 yuan / one, the program than the metal mold trial process to save 685,000 yuan, cost savings of 85.63%. The printed parts are shown in Figure 4.

Figure 4. Engine cover

Transmission drencher assembly is an important part of the lubrication system in the transmission, the material is PA66, the size of 210 mm × 80 mm × 80 mm, the conventional manufacturing process for injection moulding, including two components, drencher structure 1 and drencher structure 2, the two parts through the sealing gasket interference connection as a whole, after the connection of the overall use of the connection, the connection of the assembly of the precision requirements of the high, to prevent the oil Leakage of oil leads to a reduction of oil drenching pressure; for the complex assembly process of the oil drencher structure 1 and

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the oil drencher structure 2 and the characteristics of the injection moulding process with a long cycle time and high cost, the cycle time is 2.5 months and the cost is 300,000 Yuan; the process of metal 3D printing is used to produce parts, for the two components of the oil drencher, the process of integrated metal 3D printing is used, and the two components of the oil drencher are printed as a whole, achieving the integrated functional printing process exploration, as shown in Figure 5.

Figure 5. Transmission drencher assembly

Engine single-cylinder head material for AlSi10Mg, size 210 mm × 190 mm × 110 mm, conventional manufacturing process for the casting method, the cycle time of 3.5 months, the cost of up to 350,000, the use of metal 3D printing process is low-cost, short cycle time; manufacturing accuracy and mechanical properties of the parts in line with the design requirements. After testing, the mechanical properties of the blank is better than the casting blank, the blank dimensional accuracy reaches the casting CT7 level; this scheme saves about 309,000 yuan compared with the metal mould trial manufacturing process, and saves 88% of the cost. Its parts diagram as 6[10].

Figure 6. Engine single-cylinder head

3. FUTURE AND OUTLOOK

This study mainly includes the application of Industry 4.0 in smart factory, the application of intelligent logistics and the application of 3D printing. Since the proposal of "Industry 4.0", China's manufacturing industry has significantly improved its level of digitalisation, networking and intelligence through the establishment of a standard system, tackling key technologies, researching and developing intelligent manufacturing equipment, and promoting pilot demonstrations. In the future, with 5G, artificial intelligence, digital twins, big data and other emerging technologies and manufacturing equipment to further deepen the degree of integration, digital, networked, intelligent "parallel promotion, integration and development" of the new model of intelligent manufacturing will continue to create and popularise.

REFERENCES

[1] Lei H. (2019) Development and application of intelligent electrical technology in industry 4.0. Electronic Components and Information, 01:36-39.

[2] Yan Y. (2016) An overview of "German Industry 4.0" and "Made in China 2025". Science and Technology Wind, 298(16):185-186.

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202312_9(12).0011

[3] Xiao F. (2022) Creating Industry 4.0 smart factory, Phoenix Contact empowers automotive manufacturing to realise intelligent transformation. Electric Times, 03:17-20.

[4] Bao D. (2019) Exploration of intelligent production workshop in printing and dyeing factory. Dyeing and Finishing Technology, 41(01):6-10.

[5] Xiao F, Wang S. (2015) Research on the application of internet of things in industry 4.0. Digital Communication World, 132(12):59-61.

[6] Fang D, Huang Y, Jiang H, et al. (2022). Research on data governance and technology for intelligent logistics. Information Technology and Network Security, 41(05):9-16.

[7] Xue X, Chen X. (2022) The use of artificial intelligence technology in supply chain logistics. Journal of Taiyuan City Vocational and Technical College, 246(01):40-42.

[8] Wang F. (2018) Exploration of practical training teaching of 3D printing and reverse engineering based on new occupational standards. China Education Technology Equipment, 1-4.

[9] Duan Z, Liu Y, Xiao J, et al. (2021) Analysis of engineering application of 3D printing technology for concrete buildings. Construction Technology, 50(18):15-20.

[10] Zhao L, Liu P, Zheng J, et al. (2023) Exploration and application of metal 3D printing technology process. Automotive Process and Materials, 410(02):1-8+15.