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The Impact of Industrial 3D Design on China's Manufacturing Efficiency

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Abstract
The rapid evolution of industrial 3D design technologies in China highlights the growing importance of these innovations in modern design culture and their distinct advantages over traditional methods. This study aims to investigate the principles behind the practical application of industrial 3D design technologies and their integration into China's industrial sectors, with a particular focus on construction, aerospace, and manufacturing. The research employs a systematic approach, combining theoretical analysis with case studies from various industries to assess the benefits and challenges of these technologies. The findings reveal that industrial 3D design technologies offer several advantages, including significantly reduced material consumption, higher efficiency, and shorter production timelines compared to conventional methods. These benefits make the technologies particularly suitable for high-precision industries such as aerospace and construction, where cost-effectiveness and sustainability are critical. Furthermore, the application of 3D design allows for the use of environmentally friendly materials and provides greater flexibility in the design process, enabling the creation of complex structures and components that were previously difficult or impossible to produce. The study concludes that industrial 3D design technologies are becoming a cornerstone of China's design culture, with a growing role in industrial production. Their potential for wide-scale application in various sectors, including medical and high-tech industries, promises to revolutionize manufacturing processes and contribute to the development of sustainable, efficient production systems.

Keywords
technological innovation; digital production; eco-friendly construction; high-precision design; industrial trends.

1. Introduction

The problematic of this research lies in the significant importance of designer activity in general and industrial 3D design technologies in particular for modern industrial facilities. Today 3D design technology has found frequent application in various industries in the People's Republic of China. In particular, it has extensive use in the construction, aviation and aerospace industries as well as in other sectors of the economy. Presently over 30% of companies in the country use 3D printing for prototype development. The People's Republic of China is successfully implementing 3D printing technology in the construction of one of the largest dams in the world, a 180-metre-high Yangku Hydropower Plant dam on the Tibetan plateau. The construction work will exclusively use the robotics and unmanned machinery based on artificial intelligence technology. The completion of construction work is planned for 2024 (Sheludko, 2022). These technological solutions involving the creation of a 3D model of an industrial facility assist in developing its visual image, which will serve in the actual construction work. The development of 3D models in the context of industrial design technologies contributes to the creation of unique interior and exterior design of buildings and structures. This enables a comprehensive assessment of the draft specimen, an ability to see its advantages and

disadvantages and specific features when carrying out subsequent construction work or putting the specimen into series production.

The research team K.R. da Silva Santos et al. (2023) conducted a joint research study on 3D-scanning methods for robotic inspection of industrial sealed components. The authors have noted that new, improved approaches to scanning industrial sealed components based on the fusion of data from a 3D laser beam sensor and a movement pattern of the robot arm would yield a geometric three-dimensional shape and volume of the test piece. The specialists indicate that this solution had a practical application after successfully tested on sealed riveted joints, widely used in the car and aerospace industries in China. In turn, a team of scientists Geng et al. (2020) discussed a number of methods for systematic adaptive design in augmented reality work using 3D design technology in complex industrial operations in China. The researchers conclude that one of the obstacles to the adoption of 3D design technology in China's diverse and complex industrial operations is the lack of guidelines to ensure that the process takes place safely. These guidelines are necessary for the effective introduction of 3D design technologies into the industrial design process in the PRC.

For their part, Santos et al. (2023) reviewed the general principles of a hinge-coupled 3D model using scale histograms of shape functions for custom additive manufacturing in China. The authors point out that the 3D-model mapping structure for coupled models is an effective solution for the preliminary stages of digital design and processing of additive manufacturing models. The 3D descriptor is resistant to perturbations and distinguishable, thus helping to separate design models and to fix them during the industrial design process. At the same time, a research group Lee et al. (2023) conducted a scientific study on the application of 3D design technology in the lightweight industry. They noted that the 3D model of the brassiere cup has demonstrated high practical efficiency for the design of women's body armour. This helps to establish weaknesses of the sutures under ballistic impact and determine the degree of discomfort from tissue build-up in the area. A scholar group Zhang et al. (2021) carried scientific study on the specifics of planning the assembly of a finished product using industrial 3D design technologies. The authors noted that the automation of assembly processes of finished joints and parts involves the mandatory use of the studied technologies in order to accelerate the operations performed. According to the authors, 3D design technology has considerable prospects for the design of modern industrial facilities.

The main purpose of this research paper is to investigate the general principles and examples of the practical use of industrial 3D design technologies as a key element of China's design culture.

2. Materials and Methods

The methodology of this research has included a systems analysis approach. This method helped to investigate the key principles of applying industrial 3D design. A theoretical study explored the practical results of the application of these technologies in various sectors of modern industry. The theoretical basis of this research work comprised the analytical results of several scientific studies in the practical implementation of 3D design technologies and in particular 3D-printers to create functional models of objects for various purposes, which have found application in a range of sectors of modern industry.

The method of system analysis of the basic principles of industrial 3D design technologies helped to define an algorithm of operations that are mandatory in the creation of a physical model of the finished object. In addition, the application of the above method has established the key characteristics and properties of industrial design technology as one of the constituent elements of the design culture in China. This method also examined the key differences between this technology and traditional methods of designing industrial facilities and obtained data on the properties of the materials used in the technologies in question.

The application of theoretical research methods concerning hands-on examples of the use of industrial 3D design technologies in the creation of real objects helped to establish the capabilities of this technological equipment in the implementation of specific production operations. In particular, this study combined the techniques of summarising the theoretical information and abstracting it with highlighting the general properties and specifics of the industrial design technologies. Theoretical investigation envisioned the use of the materials in this research paper to explore the practical applications of 3D printing technology in China (Miao, 2021). This helped to explore tangible possibilities of 3D printing technology through the creation of a concrete book booth, designed and built by a team from Tsinghua University's School of Architecture under the direction of Professor Xu Wego. In addition, the authors investigated the application of 3D printing technology used for the gateway of the Happy Valley theme park in Nanjing with modified plastic as the main construction material.

The combination of selected research methods involved the use of a number of papers aimed at exploring the principles of additive manufacturing technologies in China. In particular, there was an analysis of the previously published research study by Tian et al. (2022). It enabled the sequencing of the additive manufacturing process from the prototype planning stage to advanced manufacturing of functional components in the industrial sectors. Another academic study by Yu et al. (2013) considered the basic principles of how artists in industrial 3D design interact with physical media to create the most desirable forms for the final physical designs. The empirical observation and research have established the key advantages of the practical application of industrial 3D design technologies over traditional methods of designing and creating functional physical objects.

3. Results

Industrial 3D design plays an essential role in the culture of design as an integral element in establishing the competitiveness of production. Over the past few decades, the industrial 3D design has emerged as a defining feature of the quality and range of the products made in a number of industrialised nations. This is owing to the distinct advantages of using these technologies, which include:

- wide range of graphic 3D design applications in the industrial sectors;
- flexibility of industrial process control when using these technologies;
- ability to create an accurate model of an object as close to reality as possible;
- quick and relatively easy adjustment of finished model, if necessary, without the need for major design changes;
- high speed in creating finished assemblies and parts;
- possibility of choosing from a wide variety of materials;
- relatively low consumption of production materials;
- easy way to obtain models of individual assemblies and parts from the overall design concept of the finished 3D object.

These are just some of the benefits of using industrial 3D design technology. The technology industry is in a state of continuous development, which makes it suitable for a variety of industrial applications. Viewed purely as an element of design activity, 3D design in China has a close association with industrial product designing. The specimens require customer approach much as aesthetic qualities to form a harmonious object environment (Lee et al., 2018). The aim of design work of any kind is to change the typical, artificial human environment around an individual. The industrial 3D design as an element of China's design culture involves creating opportunities to combine the creative nature of the design of the built environment with the variety of solutions to specific construction problems.

Three-dimensional architectural printing is a state-of-the-art approach in which existing printing technology sets on to multiple personal computers. This technology has wide and successful coverage in the construction industry and involves the sequential application of the material through a print head. As a result, the material comes in layers to form the finished product. This

technique involves the use of plastic or metal powder as well as other bonding materials. A modern 3D printer includes the following (Miao, 2021):

- control components;
- mechanical components;
- print heads;
- carrier;
- consumables.

The use of industrial 3D design technologies to create a physical model of an object implies a certain algorithm. In general terms, it comes down to the following:

1. Defining and calculating the geometric shapes of the object required to create a visual model. Polygonal modelling is acceptable at this stage as well as mould rotation, extrusion and build-up techniques.
2. Adding a raster image and then giving it the desired shape, texture and colouring. This makes the industrial model as realistic as possible.
3. Lining up the lighting. At this stage, the lighting requires correction, which involves the placement of light sources with account of the topography and the shape of the object created. Correct placement of the light sources helps to see all possible imperfections in the three-dimensional model of an industrial object.
4. Visualisation. The final stage of the algorithm involves adding special effects as well as additional settings. This allows for detailed display settings and elaboration of all possible auxiliary components.

A core advantage of using industrial 3D design technology as a key element of China's industrial culture is its high productivity. The continuous use of the 3D printer over a 24-hour period creates a single-storey building with a total floor space of 46.45 m2 (Miao, 2021). At the same time, the use of this kind of technology significantly reduces a number of construction waste and provides rational use of materials. The industrial 3D design technologies have been in high demand in China, opening up unprecedented opportunities for the construction industry. The People's Republic of China is now the leader in Asia in the application of these technologies in the industry and construction.

Figures 1-2 show a concrete book cabin created through the practical application of 3D design technology.

Figure 1. Concrete book cabin created through the application of industrial 3D design technology. Source: Miao (2021).

Figure 2. Concrete book cabin created through the application of industrial 3D design technology. Source: Miao (2021).

Professor Xu Wego of Tsinghua University designed the cabin shown in Figures 1-2. The specialists used several 3D printers in the creation of this model as well as materials specially developed by a team from the University's School of Architecture, led by Xu Wego. Developing the design concept for this structure resulted in the creation of a preliminary sketch, followed by the use of MAYA software tailored to the needs of industrial modelling. In addition, the team developed and implemented a rational form of space and facility structure to determine the most suitable design of the facility. The specialists then established the print direction and coding through scheduling technology to complete the digital file. The next stage involved robotic 3D printing equipment to manage the digital files. This helped to put the concrete on materials of the structure layer by layer, applying the print in stacks, which is necessary to create the curved shape of the book cabin. The concrete structure shown in Figures 1 and 2 has a total area of about 30 square metres and can accommodate 15 people for holding a wide variety of events.

Figures 3-5 show images of the eastern gate of the Happy Valley Theme Park in Nanjing. It is the world's largest architectural structure created using 3D design technology.

Figure 3. The gateway to the Happy Valley theme park. Source: Miao (2021).

Figure 4. The gateway to the Happy Valley theme park. Source: Miao (2021).

Figure 5. The gateway to the Happy Valley theme park. Source: Miao (2021).

The construction of this architectural structure involved the modified plastic. The official opening of the park took place in November 2020. The architectural design of the park's gates reflected the real prospects of industrial 3D design technology.

The continuous fibre-reinforced polymer composites often serve as building materials in the automotive, aerospace and 3D printing industries in China to create ready-to-use object models. This is possible owing to many advantages such as their lightweight, high specific strength compared to metals and metal-based alloys. The composites used in today's aircraft (in particular the composition marked A350XWB) account for no more than 50% of the total mass of the material. The structural weight of the component can drop up to 60% if using modern composites instead of conventional steel (Khan et al., 2018). Nevertheless, the costs arising from the use of advanced composites are generally significantly higher than typical metal-based materials in key aspects: raw materials, production process, equipment and processing. In particular, thermosetting composites in recycling are applicable only with reduced material properties and at high costs after the end of the product shelf life (Kalkal et al., 2021).

The last few years saw the emergence of thermoplastic composites with baseline characteristics as high creep resistance, facilitation of processing and complete recyclability. This opens up significant prospects for the next generation of environmentally friendly composites in the future. The moulding of thermoplastic composites as injection moulding or line placement is still mould-dependent, creating difficulties to design and fabricate

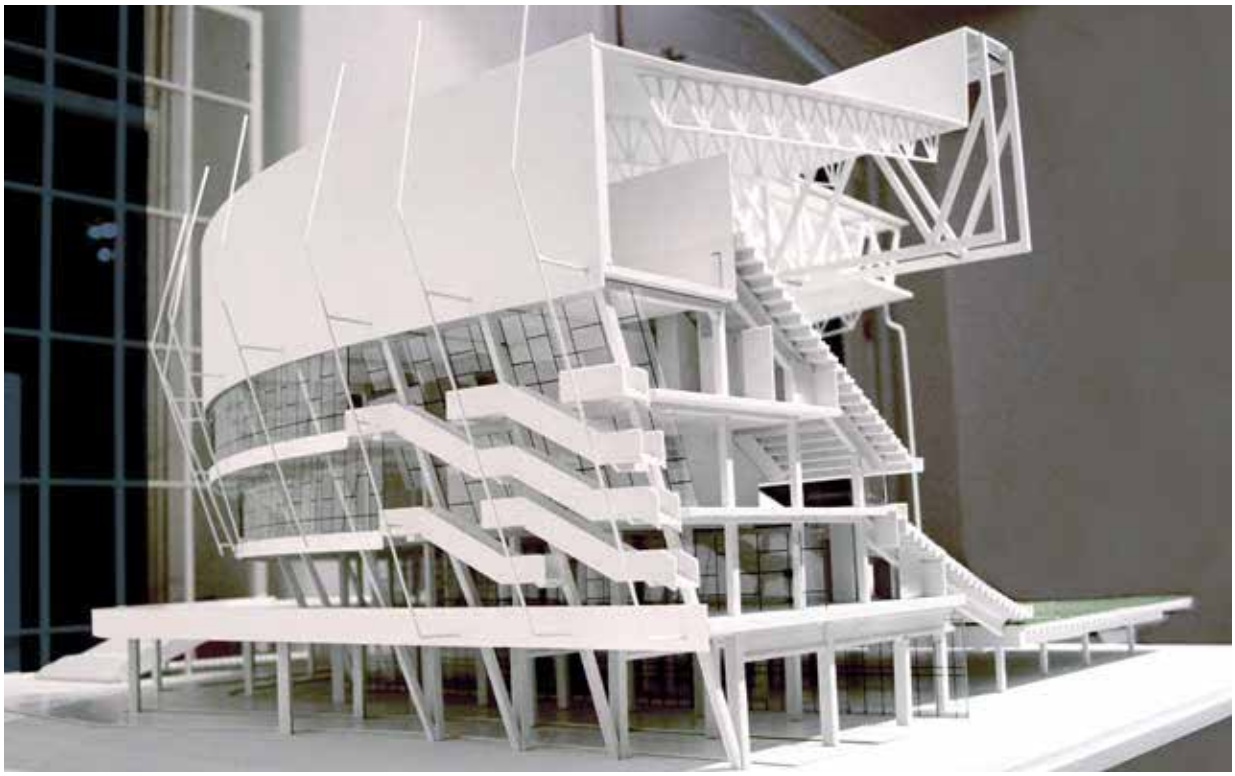

Figure 6. A three-dimensional image created using computer technology

complex composite structures. The application of industrial 3D design technologies in the design of individual objects or their components necessitates the use of special computer software in the process. The effective functioning of this software requires auxiliary equipment: computer devices, printers and tablets. Figure 6 shows the three-dimensional model created using computer technology.

The creation of a three-dimensional model of the finished object as shown in Figure 6 occurs in several steps: creating a geometric, spatial basis for the model, overlaying materials and building up lighting. With the current level of computer technology in China, there are all the prerequisites for creating high-quality 3D models of finished objects.

The industrial 3D design technology also known as “additive manufacturing” has been widespread in China since the 1980s. At present, a serious lack of innovation capacity in the manufacturing industry to develop new products has become a bottleneck holding back the development of the process industry. The industrial 3D design technologies are capable to implement the manufacture of new products quickly and efficiently and secure an effective approach to product research and development. Besides, the application of additive manufacturing technologies can decrease the financial and personnel threshold of the process industry, which promotes small businesses and activates capital resources. The additive manufacturing technologies also offer great opportunities for manufacturing revolution and creation of new products that can promote the restructuring of process industry and contribute to its transformation into intelligent manufacturing (Tian et al., 2022).

The most important advantage of these technologies is the possibility to choose the material best suited under selected structural configuration. It ensures effective achievement of the controlled shape and individual characteristics of the designed object. This technology

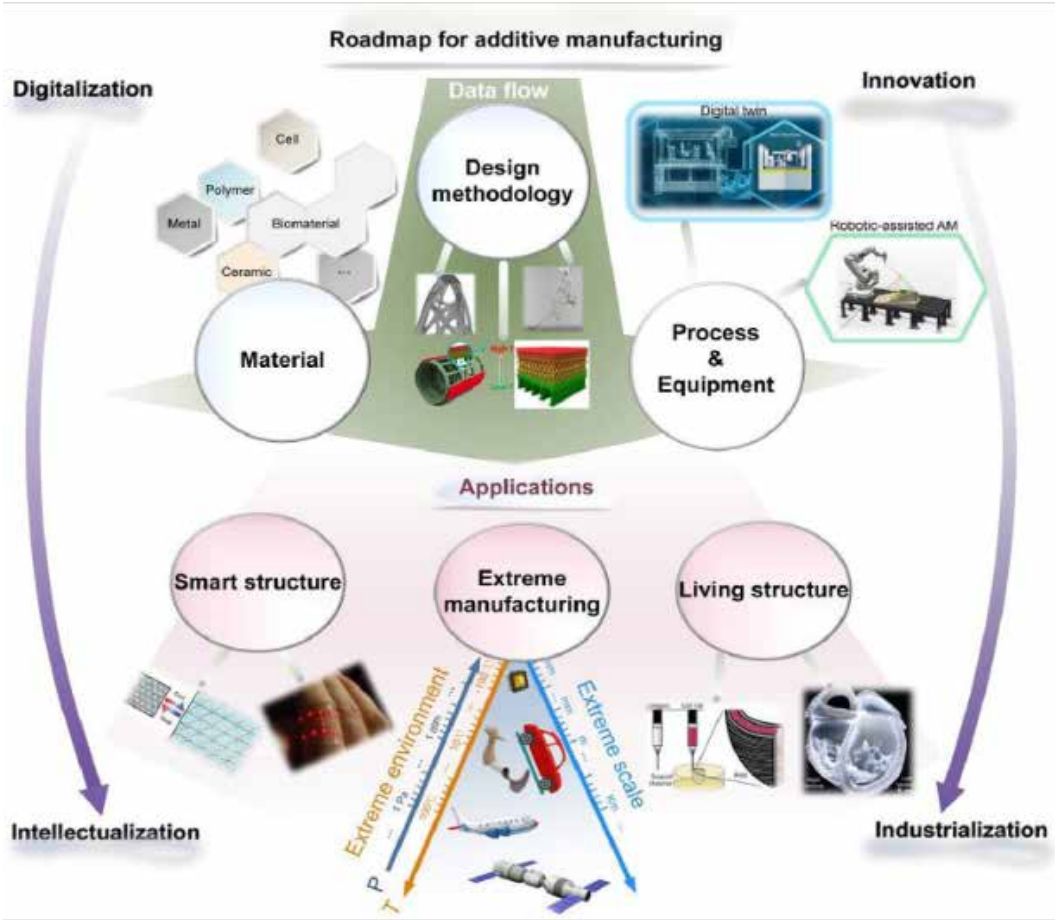

Figure 7. Schematic representation of the additive manufacturing roadmap. Source: Tian et al. (2022).

has successfully enabled the digitisation of the design process and the production of finished samples. The result was the creation of a data flow from the selected materials to the final application stage. This process has depiction in the Figure 7.

The Figure 7 outlines the sequence of transition of the additive manufacturing process from the prototyping stage to advanced manufacturing of functional components in the industrial sectors. In the future, the industrialisation and intellectualisation of equipment processes can create barriers to the industrial promotion of 3D design technology. The intelligent industrial 3D design technology can help to fulfil an autonomous production process with high precision and a considerable degree of stability. This process would involve using a closed control loop. Being an emerging and rapidly developing technology, the industrial 3D design is still far from meeting the full requirements of traditional industry in the standardisation and industrialisation of mass, conveyor production processes (Tian et al., 2022).

There is a considerable amount of effort into cutting-edge products with unique characteristics in many industries as aerospace, motor, die and mould manufacturing over the past few decades in China. The quick ability to create and unify these products with versatile properties is vital for success in a competitive environment of constant transformation and rapid

response to changing global markets. Traditionally, the product takes shape on the shop floor rather than on a computer screen, presented in the form of real physical prototypes instead of virtual digital models. In particular, the style artists often interact with physical media as clay or wood rather than digital models to achieve a desired form when developing automotive designs. With the promotion of industrial 3D design technologies, the creation of geometric models of real physical objects has assumed a significant role in reverse engineering, particularly when a prototype passes the creation or modification stage on the shop floor and a 3D image or model does not exist (Izdebska-Podsiadly, 2022). There is a growing need in reconstruction of 3D models of the existing objects in various industrial applications.

The range of practical applications of industrial 3D design technology is quite wide nowadays. The technologies of this kind are present in the following areas:

- creating visual 3D models for the subsequent assembly of complex industrial objects;
- visualisation of industrial objects, buildings and interior elements;
- designing of complex sub-assemblies and parts of different dimensions.

These technologies have a wide use in the medical industry (creating three-dimensional models of prostheses), furniture manufacturing (creating three-dimensional models to display catalogue products) and advertising (developing three-dimensional presentations to create extra effect). Three-dimensional models of complete objects are effective for obtaining drawings of individual parts or a complete structure. It is much easier to work with these industrial drawings than with the standard project documentation.

The industrial 3D design as part of China's design culture has undergone significant transformations under evolution of industrial, manufacturing and construction technologies (Thomas and Singh, 2020). The 3D printing or additive manufacturing has gained widespread recognition as a breakthrough technology and has become increasingly popular in recent years in the manufacturing industry. As a result, quality control of 3D printing becomes crucial when improving the quality of industrial products.

4. Discussion

Ahmad et al. (2020) reviewed the general principles of 3D printing technologies in nano medicine and the medical industry in general. According to the scientists, the application of 3D printing technology in these sectors provides an introductory and comprehensive view of the field of nanotechnology, which has been undergoing intensive development in recent decades. Besides, the authors point out that learning from this kind of experience opens up many additional possibilities for evaluating the industrial 3D design technologies in other areas not directly related to medicine. There are indeed real prospects for technological progress in these fields. The researchers' conclusions correlate with the findings of this research paper.

The authors Perney et al. (2023) considered a new approach to creating 3D models for the sewing industry in the context of applying the localisation principles based on graphical coding. The researchers note that the use of 3D-modelling techniques help to generate patterns by specifying the coordinates of key points, which contributes to fast, accurate creation of clothing cut-outs. According to the authors, this approach will help the fashion designers to create patterns for almost any design, which opens up broad prospects for the textile industry and demonstrates potential applications in footwear, flexible digital tablets, home textiles and a number of related fields. The scientists' conclusions are fully consistent with the findings of this research paper.
The topic is a subject by a group of scientists Pandey et al. (2022) who have addressed a number of key aspects of the application of 3D design technologies in the design of wastewater treatment plants in a joint scientific study. The scientists say that 3D printing technology is currently breaking new ground in the design of structures whose functional purpose is to release pollutants from water on an industrial scale. According to the researchers, this kind of technology has significant future prospects owing to the many advantages compared to traditional

methods of designing purification facilities. The researchers' conclusions are fully consistent with the findings of this research study.

A group of research scientists Cai et al. (2021) conducted a joint research paper on the latest personalised pottery-making system. They point to the fact that Wowtao system gives the users a real opportunity to bring their digital creativity into the real world. The system involves the use of 3D design technologies to create three-dimensional model images of pottery on mobile applications interactively by doing it simply and quickly. According to the scientists, this fact is a clear illustration of the promising application of 3D design technology in the design of physical products in China. The scientists' conclusions are fully consistent with the findings of this research paper.

In turn, Derossi et al. (2024) have carried out a study on some problematic aspects of the application of 3D design technologies in the food industry, where they observed significant prospects for the innovation in the field of food 3D printing. These include the design and development of printable food formulations to ensure high recipe accuracy and stability after printing. In this context, the goal of 3D printing technology is to create edible structures from a digital structure using CAD software. The scientists' conclusions are fully consistent with the findings of this research paper.

The authors Sanjayan et al. (2020) have addressed a number of fundamental aspects of the application of 3D printing technology using concrete as a building material in a joint research paper. They have established that 3D printing with concrete provides a lot of valuable information on new construction methods and techniques. In particular, the concrete printing process and the design of buildings constructed using these technologies offer significant prospects for the wider adoption. This applies to all stages of the process, including processing set-up, computational design and the printing stage itself. The scientists' conclusions are fully consistent with the findings of this research paper.
A group of research scientists Yu et al. (2013) addressed certain aspects of the application of 3D visualisation principles in small-size aircraft research. The scientists note an increase in using 3D-technology in the aerospace industry to improve the quality and performance of aircraft. As the authors suggest, the practical application of 3D design technologies in the design of aircraft and spacecraft helps significantly to improve their structure at the proto-design stage. This contributes to significant improvement of the safety of future aircraft applications, when minimising the likelihood of operation accidents. The scientists' conclusions are fully consistent with the findings of this research paper.

Thus, the discussion of the findings obtained in this research paper has demonstrated their fundamental correspondence in the context of their analytical comparison with the results of several scientific studies in the field of industrial design as an element of design culture. The authors confirmed the scientific validity of the results of this study and the admissibility of their practical use in the implementation of technologies of industrial 3D design in the designing of models of finished objects.

5. Conclusions

This research has established that industrial 3D design technology has become widespread in China, taking its place as one of the building elements of the country's design culture. The People's Republic China is currently leading in the design of construction and industrial facilities using 3D printing technology in Asia. The industrial 3D design technologies have intense application in creating multi-functional models of construction projects as well as in the aerospace industry and a number of other industrial sectors. The range of practical applications for the technologies in question is constantly expanding, given the society's growing need for high-tech products.

The industrial 3D design technologies are the part of the country's design culture and have a number of advantages over traditional technologies. These include significantly lower consumption of raw materials, use of environmentally friendly materials, moderate

production costs, ability to create finished samples and erecting industrial facilities in a lesser timeframe than traditional methods. Besides, the application of this kind of technology provides additional possibilities in a wide variety of materials, which opens up significant prospects in the development of environmentally friendly structures in a wide range of industrial sectors. These technologies involve an extensive range of industrial applications in design operations and they provide flexibility in industrial production process management, allowing the creation of accurate models of the object as close to reality as possible.

The new technologies offer additional possibilities in numerous industrial fields. They will help to create fully autonomous production lines aimed at the most contemporary and technologically advanced products in the future. However, the industrial 3D design technology of today is still a long way from massive application in the manufacture. This opens up new directions for research into the development of additive manufacturing technologies and their wider application in the industry. The implementation of these research directions will fully contribute to expanding the range of practical applications of industrial 3D design technologies also in related fields, which require the use of non-standard technical solutions with high-tech materials. This is fully applicable to the medical sector and a number of the fields, which require high precision in design work. The prospects for further research in this direction provide the significant advantages of industrial 3D design technologies over traditional methods of creating construction and industrial objects.

Conflict of Interests and ethics

The author declares no conflict of interests. The author also declares full adherence to all journal research ethics policies.

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