

**APPLICATION OF COMPUTER-AIDED DESIGN METHOD TO OPTIMIZE THE  
MODELING AND DESIGN STAGES FOR INDUSTRIAL PRODUCTS**

**APLICAÇÃO DO MÉTODO DE DESENHO ASSISTIDO POR COMPUTADOR  
PARA OTIMIZAR AS ETAPAS DE MODELAGEM E PROJETO DE PRODUTOS  
INDUSTRIAIS**

**APLICACIÓN DEL MÉTODO DE DISEÑO ASISTIDO POR COMPUTADORA  
PARA OPTIMIZAR LAS ETAPAS DE MODELADO Y DISEÑO DE PRODUCTOS  
INDUSTRIALES**

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## Abstract

The paper aims to analyze the stages of modeling and visualization of industrial product prototypes. The authors describe the process of creating a virtual model, as close as possible to a realistic image of the product, considering the requirements of industrial design. The SolidWorks computer-aided design system in the PhotoView 360 application is used to build the model and develop the design project. The study notes that the quality of computer modeling and visualization of 3D parts directly depends on the main functional parameters, including many input data needed to develop a technical specification, the graphic component containing the results of framework and 3D modeling, the time of parameter processing for further visualization, etc. The study identifies the advantages of using various effects to visualize industrial objects.

**Keywords:** Industrial design, Industrial products, Realistic 3D model, Object visualization, SolidWorks, Realistic modeling, Design project.

## Resumo

O artigo tem como objetivo analisar as etapas de modelagem e visualização de protótipos de produtos industriais. Os autores descrevem o processo de criação de um modelo virtual, o mais próximo possível de uma imagem realista do produto, considerando as exigências do desenho industrial. O sistema de projeto assistido por computador SolidWorks no aplicativo PhotoView 360 é usado para construir o modelo e desenvolver o projeto de projeto. O estudo observa que a qualidade da modelagem por computador e visualização de peças 3D depende diretamente dos principais parâmetros funcionais, incluindo muitos dados de entrada necessários para desenvolver uma especificação técnica, o componente gráfico contendo os resultados da estrutura e modelagem 3D, o tempo de processamento do parâmetro para posterior visualização, etc. O estudo identifica as vantagens de usar vários efeitos para visualizar objetos industriais.

**Palavras-chave:** Desenho industrial, Produtos industriais, Modelo 3D realista, Visualização de objetos, SolidWorks, Modelagem realista, Projeto de design.

## Resumen

El artículo tiene como objetivo analizar las etapas de modelado y visualización de prototipos de productos industriales. Los autores describen el proceso de creación de un modelo virtual, lo más cercano posible a una imagen realista del producto, considerando los requisitos del diseño industrial. El sistema de diseño asistido por computadora de SolidWorks en la aplicación PhotoView 360 se utiliza para construir el modelo y desarrollar el proyecto de diseño. El estudio señala que la calidad del modelado por computadora y la visualización de piezas 3D depende directamente de los principales parámetros funcionales, incluidos muchos datos de entrada necesarios para desarrollar una especificación técnica, el componente gráfico que contiene los resultados del marco y el modelado 3D, el tiempo de procesamiento de parámetros para una mayor visualización, etc. El estudio identifica las ventajas de utilizar varios efectos para visualizar objetos industriales.

**Palabras clave:** Diseño industrial, Productos industriales, Modelo 3D realista, Visualización de objetos, SolidWorks, Modelado realista, Proyecto de diseño.

## 1. INTRODUCTION

The preparation of design documentation in production to increase efficiency when demonstrating developments to the customer or the user is carried out with the help of modern information technologies of industrial design (Kostromina et al., 2022). The critical goal is to present the product in the most competitive form to attract the maximum number of customers (Vaslavskaya et al., 2022). The modern market for computer-aided design (CAD) systems provides a wide variety of effective tools for visualizing developed models of industrial equipment and technical parts. That is why visualization is one of the most important stages of CAD, through which the designer obtains a complete image of the product (Zenin & Nekrasov, 2022).

The growing demand for Russian industrial design products stems from several reasons (Astakhova et al., 2017): – identification: every entrepreneur starting their business in the first place is faced with the issue of organizing efficient production and sales system, and only after that does the need arise to create elements of identification: corporate identity and unique products. Russian industrialists have now come very close to this phase; – assortment (assortment monotony of the modern market): the uniqueness of a product in such circumstances is gaining importance, putting the company logo on the product is no longer enough, the design product has to be given unique functional properties, which can only be obtained by the method of industrial design; – the high price of the services of foreign designers: the high cost of design services of foreign design companies causes increased demand in the Russian market for domestic developments (Alterman, 2017). To obtain a realistic model of a product, part, or technological equipment, the graphic image, namely the 3D model of the product, goes through a certain editing procedure. The final stage of the visualization process is rendering. Application software functions produce a realistic image of the designed industrial sample (Petrenko et al., 2023). The use of the corresponding module increases the quality of engineering of design products. Industrial design has a variety of rendering software, in particular: Artlantis Studio, Autodesk 3ds Max, V-Ray, Maxwell Render, FryRender, IndigoRenderer, LuxRender, KOMPAS-3D, the Artisan Rendering app, the PhotoView 360 app, etc.

These digital environments provide various types of operations and are often used in applications ranging from graphics to visualization to industrial product presentation (Sergeeva, 2018). Application of computer-aided design method to optimize the modeling and design stages for industrial products Rendering is a stage in industrial design that provides the editing of a 3D product in specialized software environments. The module that performs rendering is called a render or renderer (Vasilenko, Muradova, 2019). Therefore, the relevant task is to analyze the stages of transforming an ordinary 3D model into the most realistic one, using various methods of the computer-aided design system. This can help improve the image quality and get a much better idea of the model, assess the appearance and detail design parameters, and establish effective communication between the customer and the developer, i.e. establish feedback. The objective of improving the quality of visualization, particularly rendering and optimization of product designs in industrial design based on the finite element method is a priority in recent research.

The first step in creating algorithms for building realistic models of design products is to analyze the various stages of rendering (Gerasimova et al., 2019; Oreshkin, 2021), as well as to consider the features of the application of 3D rendering to compare the finished product models when adjusting their visual parameters (Shesteriakova, 2021). The goal of the study is to form a scientific base that contributes to exploring the peculiarities of the influence of product parameter relationships on the quality of virtual model rendering in obtaining images of industrial products.

## 2. METHODS

Computer modeling and visualization in industrial design directly depend on the relationship of parameters, namely, the geometry of the object examined, time components, and organizational factors, as a result of which the design product can be described using a factor mathematical model (Reshetov, 2021):

$$Mv = (Vd, Gr, Ti, Ren, Org) \quad (1)$$

where  $Vd$  is the set of input data needed to develop the project's terms of reference;

$Gr$  – the graphic component containing the results of wireframe and 3D modeling;

*Ti* – time component of data processing for subsequent visualization;

*Ren* – rendering stage, which combines the data on the model, giving its description and including the selected programs – renderers;

*Org* – the set of organizational factors affecting the process of visualizing details of an industrial design product and containing information about the feedback between the developer and the customer, carried out from the initial to the final stage of creating the rendering of the product.

The interrelationships of these components provide a quality process of data processing to obtain a graphic image and ultimately a render model. The rendering process implies the visualization and creation of industrial product models, and the model itself is obtained via a specific programming language or in the form of structures, lists, arrays, etc. The description of a model contains geometric data as 3D model coordinates, as well as parameters of performed changes and transformations, i.e., movement, scaling, rotations, etc., coordinates of lighting parameters, and material properties (textures, colors). By working through the available factual data, the renderer program visualizes the model. The theoretical basis of rendering is the solution of the equation describing the propagation of light in a 3D model (Astakhova et al., 2017):

$$L0(x, \omega, \lambda, t) = Le(x, \omega, \lambda, t) + \int \Omega fr(x, \omega', \omega, \lambda, t) Li(x, \omega', \omega, \lambda, t) (-\omega \cdot n) d\omega' \quad (2)$$

where  $\lambda$  is light wavelength;

$t$  – time;

$L0(x, \omega, \lambda, t)$  – the amount of radiation of a given wavelength;

$Le(x, \omega, \lambda, t)$  – light emitted;

$\int \Omega fr(x, \omega', \omega, \lambda, t) Li(x, \omega', \omega, \lambda, t) (-\omega \cdot n) d\omega'$  – integral over the hemisphere of the input directions;

$L0(x, \omega, \lambda, t)$  – the bi-directional distribution of the reflection function, that is, the amount of radiation of reflected light from  $\omega'$  to  $\omega$  at point  $x$  in the direction of  $\omega'$  in

time

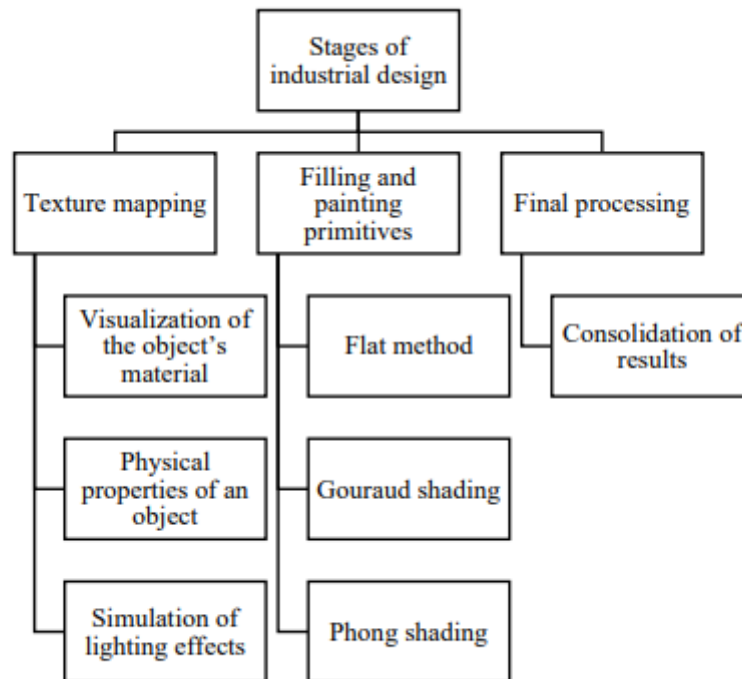
$t; (-\omega \cdot n)$  – absorption of incoming radiation at a given angle.

The  $f_r$  is important in rendering theory and is titled the bidirectional reflectance distribution function (BRDF). The BRDF describes the optical properties of surface reflection and is an abstract mathematical unit. That is, to describe the equation of rendering in industrial design, we can use illumination at a point consisting of the energy of the rays produced by light sources, as well as the energy of the reflected rays. At the same time, it is necessary to consider the surface properties, the geometry of the object, and the like. 3.

### 3. RESULTS AND DISCUSSION

Given the aforementioned factors (1), we examined the process of creating a model as close to a realistic image as possible, using the example of developing an industrial part built in the SolidWorks CAD system in the PhotoView 360 application. In this case, the SolidWorks Application of computer-aided design method to optimize the modeling and design stages for industrial products has the following advantages: it provides the modeling of products (parts), creates design documentation, forms an attractive appearance using the industrial design method, calculates models for strength and stability, simulates the machining process, etc (Khrustalev et al., 2022).

The industrial design of any degree of complexity, considering the specifics of the part production, differs from other CAD systems in the simplicity of the construction process. Using the factor mathematical model (1), equation (2) describes light propagation in 3D space. Further, a scheme of the sequence of creation of improved rendering of industrial design objects was constructed, containing the relationships between the stages and methods used in the process under study (Figure 1).



**Figure 1.** Diagram of the industrial design sequence for objects

At each of these stages, the renderer carries out different functions, namely: the stage of texture mapping is divided into visualizing the material of the product, emphasizing the physical properties of the object, and modeling light effects. The creation of design primitives involves methods by which color changes are performed; here the flat method, the Gouraud method, and the Phong method are applied (Gerasimova et al., 2019). The emergence and application of optimization methods can be traced back to the time of Newton, Lagrange, and Cauchy (2010).

The development of differential optimization methods was enabled by the contribution of Newton and Leibniz to the development of mathematical analysis. The foundations of the calculus of variations relevant to the minimization of functionals were laid by D. Bernoulli, L. Stages of industrial design Texture mapping Visualization of the object's material Physical properties of an object Simulation of lighting effects Filling and painting primitives Flat method Gouraud shading Phong shading Final processing Consolidation of results Xiang, Jinghao, Nazarov and Lagrange.

An optimization method for constraint satisfaction problems involving the addition of unknown factors is named after its inventor, Lagrange & Cauchy (2010) first applied the method of steepest descent to solve unconstrained minimization problems. Despite these first

achievements, only the advent of high-speed digital computers provided an opportunity to implement optimization techniques, which stimulated further research toward the creation and use of new methods. As a result, significant achievements were attained and then reflected in a vast number of papers devoted to optimization methods.

This progress has given rise to several well-defined new areas of optimization theory, in particular, a whole class of heuristic optimization methods based on the use of stochastic algorithms that extend functions and fundamentally change the understanding of the role of industrial design. The smoothing process can be divided into the stages of elimination of stair-stepping effects and adding auxiliary effects. The final editing step is to merge all the results of constructing the model of an industrial design object. Most researchers concur that it is desirable to develop optimization methods that will be effective in solving stochastic design problems. In particular, these conditions are satisfied by metaheuristic methods – the most general and promising algorithms of stochastic optimization, which to some extent use randomness to achieve the optimal solution in the complex problems of modern science and technology. As a rule, such problems have a multitude of design parameters.

With little auxiliary information available, it is not always known what the optimal solution looks like or how this solution should be sought. Thus, the available heuristic information is insufficient, and sequential enumeration of data is not suitable because of the large search field, which is true for modern industrial design. For most industrial design problems, the solution can only be found with non-linear programming methods. Yet there are some engineering applications for which other optimization methods are most suitable, such as linear, geometric, dynamic, integer, and stochastic programming methods. For example, let us examine the process of industrial design of the product type "rim", the model of which is subject to visual editing (Figure 2).





**Figure 2.** Model of the "Rim" part before visual editing

The first stage of the research, according to (1), is to analyze the methods of developing the process of part rendering in the PhotoView 360 application. For a detailed analysis of the rendering process, we outline the following steps for using the PhotoView 360 application. The first step is to select the part material type (Figure 3). In the upper right corner, select "Appearances, Scenes and Decals" → "Appearances (color)" → "Metal" → "Chrome" → "Chrome plate".



**Figure 3.** Selecting the type of material in the PhotoView 360 app

Using the "View settings" option further select all parameters of the model display (Figure 4).



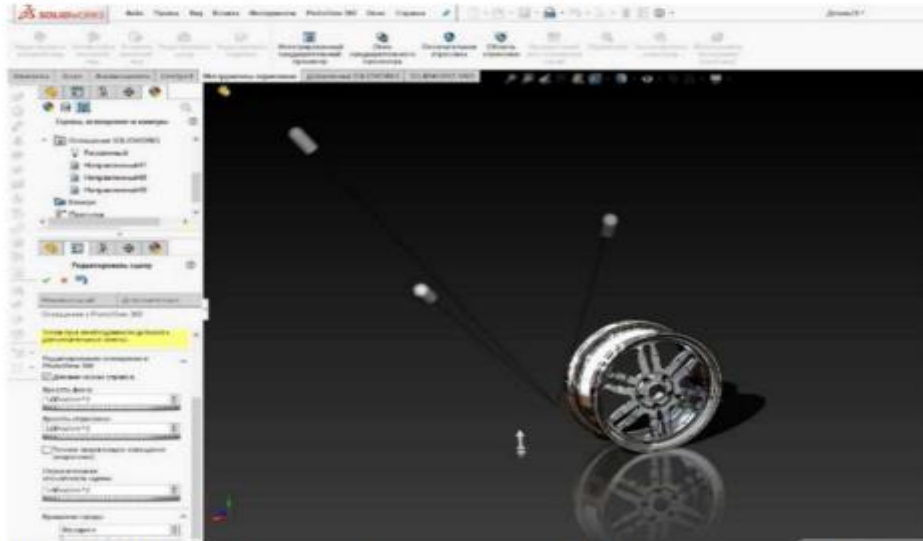
**Figure 4.** Selection of the parameters for displaying the part model

Then we select the scenes that best demonstrate the product, viz: "Appearances, Scenes and Decals" → "Scenes". It is possible to add an emblem, manufacturer's logo, inscription, etc. (Figure 5).



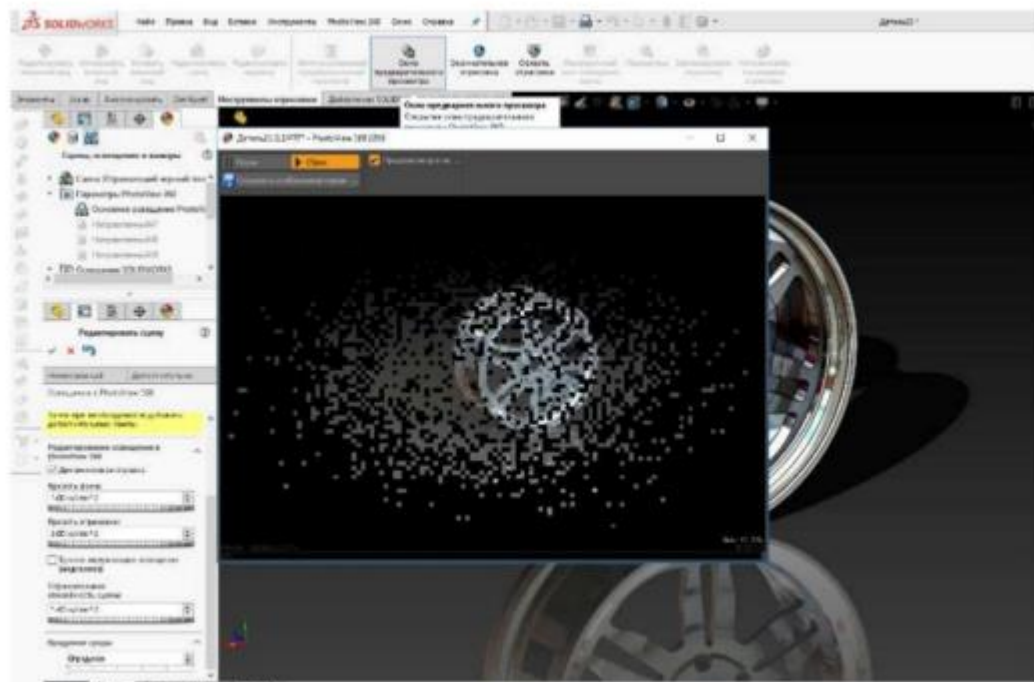
**Figure 5.** Selection of scene and emblem, manufacturer's logo

Using the "Render Tools" insert, adjust the parameters of lighting, background, shadows on the ground, the size of the image, etc (Figure 6).



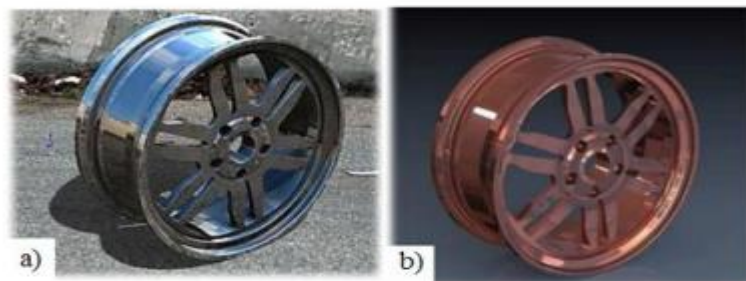
**Figure 6.** Selecting the settings for lighting, background, shadows, and display size

To preview the result of the rendering, use the "Integrated preview" command and the "Preview window" option. Use them to build a model of the part using the user-defined parameters of the part (Figure 7).



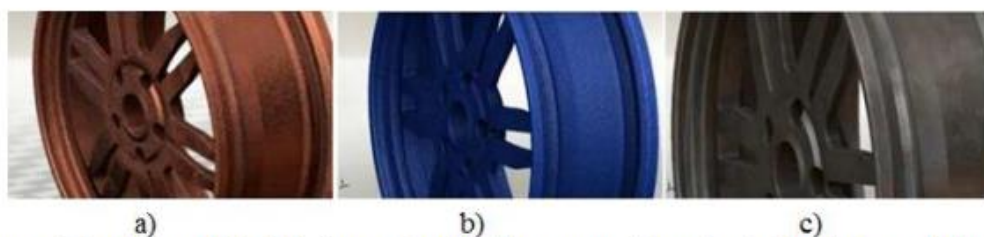
**Figure 7.** Command to view an enhanced model rendering

By adjusting the parameters, it is possible to obtain a fair amount of rendering results as well as a visualization very close to the actual representation of the part or assembly. Figure 8 shows examples of renderings with parameter adjustments that are responsible for reproducing effects and showing material types. Figure 8a shows a chrome "Rim" part. Figure 9b shows a specular copper "Rim" part. When creating the background environment for a model by adding material, surface shadow effects, and scene modifications, the image of the part is transformed as well. Detail rendering in PhotoView 360 gives the developer a clear view of the product in the marketplace and allows the manufacturer to present their product in a high-quality and thorough fashion.



**Figure 8.** The "Rim" part after editing in PhotoView 360:

- a) a chrome part;
  - b) a specular copper part
- Figure 9 depicts renders of the "Rim" part model, successfully conveying the surface shape, material, and relief of the product.



**Figure 9.** Renderings of the "Rim" part: a) made of cast copper; b) made of galvanized metal; c) made of coarse plastic.

Thus, we can highlight the following advantages of using rendering to process 3D models of parts: - significant improvement in product presentability; - the ability to assess the quality of the part model during assembly; - a visual representation of the appearance of the part; - no need to produce prototypes of the part for presentation; - prompt solutions to design problems. Effective use of rendering is achievable given two factors: sufficient training of the

developer and up-to-date technical software for comfortable operation and viewing of rendering results. However, the accuracy of an industrial design product model intended for production may not be optimal (Erlikh & Erlikh, 2021). With regard to additive technologies, there is also a growing demand for topological optimization tools that deliver optimal designs in terms of the distribution of mass and preservation of the intended safety factor. These technologies allow manufacturing bionic products at minimal costs. However, the combination of topological optimization tools and additive technologies poses the following problem: the result of topological optimization is not suitable for production in its original form due to the presence of "sawtooth" surfaces in the digital model of the product on the design grid (Trofimov et al., 2022). These surfaces present an array of stress concentrators distributed over the entire surface of the model, which without prior smoothing will be transferred to the final product, adversely affecting its mechanical properties. The solution of the spectrum of design improvement methods for subsequent additive manufacturing is associated with modeling the system of optimal control of mechanisms based on the parameterization of material processing systems. This requires appropriate research both Application of computer-aided design method to optimize the modeling and design stages for industrial products in the direction of constructing mathematical models that account for the physical, geometric, mechanical, electromechanical, and other features of composite structures and in the development of optimal design methods.

#### 4. CONCLUSION

Design engineering is the process of creating the structure of the product that best meets the criteria for the quality of its performance. For structures with subsequent additive manufacturing, such criteria are mass characteristics: stiffness, strength, the frequency range of operation, vibration resistance, energy dissipation level, etc. In many cases, the adopted criteria may contradict each other, and the vast number of parameters on which these criteria depend makes it impossible to implement simple selection methods to identify the best design. Because of this, there is still no universal model and method for designing topologically optimized products. The creation of efficient load-carrying structures with a high level of surface smoothing is impossible without the use of optimization methods. The ever-increasing demands



of production, especially in high-tech industries, have forced engineers to look for highly accurate ways to make decisions, especially for efficient and cost-effective optimization methods for product development and production. The visual representation of a product model render provides a unique opportunity to understand its design. Complex parts and bulky assemblies additionally require an in-depth understanding of schematics and drawings: a high-quality rendering allows all parties involved to understand what is presented in the image. This can be done by the developer, the customer, or the future user. To substantiate the modern concept of industrial design, this paper analyzes the rendering process in the SolidWorks CAD system (PhotoView 360 application) based on the example of the "Rim" product model. Renderings of the developed model are created, conveying the shape of the part surface, material, product topography, etc. A factor mathematical model for analyzing the relationships between the various stages of product design is created, including a description of the dependence of parameters for computer modeling of the part and the subsequent visualization of the product. The study uses a rendering equation describing the propagation of light on a 3D scene, based on which the sequence of rendering of industrial design objects is charted. The proposed scheme presents the main stages of image editing and describes methods of designing design project primitives. The results of the research allow us to systematize the sequence of rendering stages in CAD systems for graphic processing and subsequent visualization of models, specifically in the field of mechanical engineering.

## REFERENCES

- Alterman, A.D. (2017). 3D modelirovanie [3D modeling]. *Innovatsionnoe razvitie*, 12(17), 12-13.
- Astakhova, T.N., Kapanov, A.A., Kosolapov, V.V. (2017). Realizatsiia tekhnicheskoi idei pri pomoshchi 3D-prototipirovaniia [Implementing a technical idea using 3D prototyping], In: *Perspektivnye napravleniia razvitiia otechestvennykh informatsionnykh tekhnologii*. Materials of the III interregional scientific-practical conference, pp. 117-119.
- Sevastopol. Erlikh, A., Erlikh, N. (2021). Determining the optimal location of an urban transport interchange hub. *Revista Ingeniería UC*, 28(3), 412–417. <https://doi.org/10.54139/revinguc.v28i3.42>
- Gerasimova, V.O., Liubin, N.S., Petrova, V.S. (2019). Tekhnologiiia 3D-pechati v stroitelstve i arkhitekture [3D-printing technology in construction and architecture]. *Engineering journal of Don*, 1, 53-67.

- Khrustalev, B., Grabovy, P., Grabovy, K., Kargin, A. (2022). Features of the use of information modeling technology in the activities of the construction complex enterprises in risk conditions. *Nexo Revista Científica*, 35(03), 777–786. <https://doi.org/10.5377/nexo.v35i03.15007>
- Kostromina, E., Krasnovskiy, E., Pertsev, V., Kovalevskaya, N., Makushkin, S. (2022). Development of a management model for the marketing activities of an industrial enterprise based on incoming controlled and uncontrolled variables. <https://doi.org/10.20397/2177-6652/2022.v22i4.2396>
- Oreshkin, P.V. (2021). Razvitiye vozmozhnostei 3D-modelirovaniia i 3D-pechati v dizaine: istoriia evoliutsii [The development of capabilities of 3D-modeling and 3D-printing in design: the history of evolution]. *Decorative Art and environment. Gerald of the MGHPA*, 1-2, 239-246.
- Petrenko, V., Tebueva, F., Antonov, V., Ryabtsev, S., Sakolchik, A., Satybalina, D. (2023). Evaluation of the iterative method of task distribution in a swarm of unmanned aerial vehicles in a clustered field of targets. *Journal of King Saud University - Computer and Information Sciences*, 35(3), 283-291. <https://doi.org/10.1016/j.jksuci.2023.02.022>
- Reshetov, M.M. (2021). Analiz tendentsii tekhnologicheskogo razvitiia otrasli promyshlennogo dizaina v usloviakh tsifrovoi transformatsii [Analysis of trends in technological development of industrial design industry in the context of digital transformation], in: *Tsifrovaia transformatsiia promyshlennosti: trend ili neobkhodimost*, pp. 242-247. Moscow: KnoRus.
- Sergeeva, O.Iu. (2018). Additivnye tekhnologii i 3D-modelirovanie [Additive technology and 3D modeling]. *Nanotechnologies in Construction: A Scientific Internet Journal*, 10(4), 142-158.
- Shesteriakova, R.A. (2021). Prichiny aktualizatsii 3D grafiki kak tekhnicheskogo metoda i sredstva vizualnoi kommunikatsii v graficheskom dizaine [Reasons for the actualization of 3D graphics as a technical method and means of visual communication in graphic design], in: *3D tekhnologii v reshenii nauchno-prakticheskikh zadach*. All-Russian Scientific and Practical Conference, pp. 254-259.
- Trofimov, I., Artykhov, A., Gostilovich, A., Chizhov, S. (2022). Automation and digitalization of processes in the management of service organizations. *Revista Gestão & Tecnologia*, 22(4), 372-383. <https://doi.org/10.20397/2177-6652/2022.v22i4.2424>
- Application of computer-aided design method to optimize the modeling and design stages for industrial products *Journal of Management & Technology*, vol. 23, n.1, p. 366-379, jan./mar.2023
- Vasilenko, E.V., Muradova, V.V. (2019). 3D-pechat i ee primenenie v dizaine [3D-printing and its application in design]. *Modern Science*, 7-2, 39-42.
- Vaslavskaya, I., Vaslavskiy, Y., Pilipenko, A. (2022). Institutional Matrices: Modeling Organizational Forms of Public-Private Partnerships for Public Goods' Quality Improvement. *QUALITY Access to Success*, 23(190), 371-383.
- Zenin, S., Nekrasov, M. (2022). Developing Models Of The Interaction Between Local And Territorial Public Self-Government Bodies To Determine Legal And Organizational Principles Of Their Effective Partnership. *Lex Humana*, 14(2), 506-519.