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Creating 3D models of production equipment and infrastructure using Blender

Bauyrzhan Amirkhanov[1], Tomiris Nurgazy[1*], Gulshat Amirkhanova[1], Murat Kunelbayev[1,2], Gulnur Tyulepberdinova[1]

[1]*Al-Farabi Kazakh National University, Kazakhstan.*
[2]*Institute of Information and Computational Technologies, Kazakhstan.*

Corresponding author: Tomiris Nurgazy (*Email: nurgazytomiris@gmail.com*)

Abstract

The growing popularity of intelligent manufacturing has been focused on digital twins since the beginning of the 4th Industrial Revolution. High-quality 3D visualization of production plays a key role in their creation. The presented article describes the use and step-by-step formation of models using Blender with CAD functions when creating a digital double using the example of the equipment. 3D rendering of production equipment allows us to see the equipment from different viewing angles, just like in real life. The purpose of the study is to familiarize people interested in digital doubles and 3D modeling with Blender and Precision Drawing Tools, as well as with the method of using these tools to create a digital copy of a food enterprise. During the research, six steps of creating a 3D model of production equipment and infrastructure were considered: modeling, texturing, optimization, environment, animation, and rendering. This methodology enables increased accuracy and realism in digital twins, allowing for in-depth analysis, simulation, and optimization of production processes. Ultimately, it helps drive smarter decision-making, increase efficiency in terms of resources, and the development of smart manufacturing technology.

Keywords: 3D model, Blender, Production equipment, Texturing, Visualization.

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1. Introduction

From year to year, production facilities utilize a wide variety of technologies to increase efficiency. With the advent of Industry 4.0, many production facilities in the modern world aim to enhance productivity through the active use of the digital twin [1]. An industrial digital twin is an accurate representation of a specific production site, system, or enterprise in electronic form. This representation aims to facilitate the management of production activities, forecasting, and optimization of its operations [2].

The key technologies of intelligent production with support for digital twins are based on five interrelated levels: physical (real objects), data (process information), modeling (virtual copies in 2D or 3D), functional (algorithms and logic), and applications (interfaces and services). Each level plays its own unique role in creating a complete system [3, 4]. 3D models have several advantages over 2D. For example, a 3D model offers multiple viewing angles, allowing you to view the model from all sides: from above, below, the side, the front, the back, diagonally, etc. Additionally, a 3D model has a more realistic appearance with textures and lighting that can be adjusted at any time as desired. Therefore, creating a 3D model is effective. The process of creating a 3D model for a digital twin of an enterprise takes a considerable amount of time. Essentially, it consists of five stages: modeling, texturing, optimization, animation, and adding interactivity [5].

Since the mid-20th century, 3D modeling has been actively used in various fields, including the food industry, film industry, gaming industry, medicine, and infrastructure [6-9]. 3Ds Max, Maya, Cinema 4D, AutoCAD, and Blender programs are mostly used for 3D modeling. 3Ds Max is one of the first 3D modeling programs. Even though many famous films were made thanks to it, this software is now outdated. Compared to other programs, it has fewer options [10, 11]. Maya is a program used by world-famous studios such as DreamWorks Animation and Disney. It's great for 3D modeling and animation, but it's a bit difficult to use. Cinema 4D is a universal program for 3D modeling. Although the interface of this software is clear and easy to use, its modeling capabilities are limited [12].

AutoCAD is a basic yet powerful tool for precise drawing. It is mainly used in engineering, architecture, and design, but its disadvantage is that it is paid and has limited support for different file formats. The Blender tool is one of the most important programs used to visualize the digital twins of industrial equipment and infrastructure, helping to optimize production processes and manage industrial facilities [13, 14]. This is a free and accessible program that allows users to create and work with three-dimensional objects. This program is the most popular and widely used among independent 3D designers and developers. It is convenient to collaborate with it not only in 3D shaping but also in 2D. Year after year, Blender increases its capabilities and the number of users [15, 16].

2. Materials and Methods

Although Blender can work with three-dimensional shapes, animate them, and create computer games, it occupies less space than other 3D modeling programs [17].

- Three-dimensional shaping. 3D shaping has the function of modeling through sculpting, polygons, and curvilinear lines. As in other professional programs, there are opportunities to use modifiers and work with an object through logical operations.
- Animation. The light automatic bone assembly function and reverse kinematics consideration function are developed in the given program. Similarly, a function for working with the dynamics of various body states and systems of small particles is added [18].
- Drawing function. In the sculpting department, thanks to various pens, the shape can be created as if we were constructing a single sculpture.
- Create texture and work with it. In the texture section, the UV linear sheet of the model can be made light automatically and drawn on its surface. In addition, there is an opportunity to combine several textures and create a new texture [19].
- Game engine. In the latest versions of Blender, a new application can be created using interactive functions.
- Video editor. There are conventional video editors, but few people know that Blender has this functionality [20].
- There are tools for visualization. There are two different ways to view the model. One of them allows us to immediately see the result in the process of working by setting the desired parameter from the screen itself. However, strong computer specifications are required to work with it. The second method shows the result of the work using conventional rendering. In addition, it is compatible with the work of various developers [21].

In this paper, the steps of 3D shaping of a chocolate tank and the infrastructure of the enterprise using the listed properties of Blender are considered. The scientific novelty of this work is that an additional module (add-on) called Precision Drawing Tools (PDT) was used to create 3D models. Models of production equipment for a digital twin must be an exact copy of the equipment of the present production in order to be able to control and predict. This add-on allows you to work with CAD modeling capabilities on Blender for free.

This means that it makes it possible to create models not with approximate, but with accurate data, such as the exact distance of vertices, objects from each other, and angles with exact degrees. This paper discusses methods for creating a model, types of texturing, and UV mapping. In addition, it describes methods for reducing polygons, automatically removing invisible edges, and using modifiers to reduce the geometric complexity of objects, which together allows you to significantly reduce the amount of data required to store and process the model. An important part of the work is a comparative analysis of Blender's capabilities in comparison with other popular 3D modeling tools, such as 3ds Max and SolidWorks.

Data is provided illustrating the advantages of Blender in terms of efficiency, and its characteristics are described. Such aspects as ease of integration with third-party plugins, the efficiency of using GPU for accelerated rendering, and the ability to export models in various formats are noted. Thus, the results of the study emphasize the efficiency of using Blender for developing 3D models. A unique example of creating a digital twin of food industry equipment adapted to a specific container for storing chocolate is given. The article describes the process of creating a 3D model with detailed consideration of the functional and design features of the equipment, using the Eevee rendering engine to create visualizations suitable for interactive control and augmented reality experiences. The graphs for the mathematical models were made using Python.

3. Results

The process of 3D shaping the digital twin in Blender is a lengthy process. As shown in Figure 1, it can be divided into six main stages.

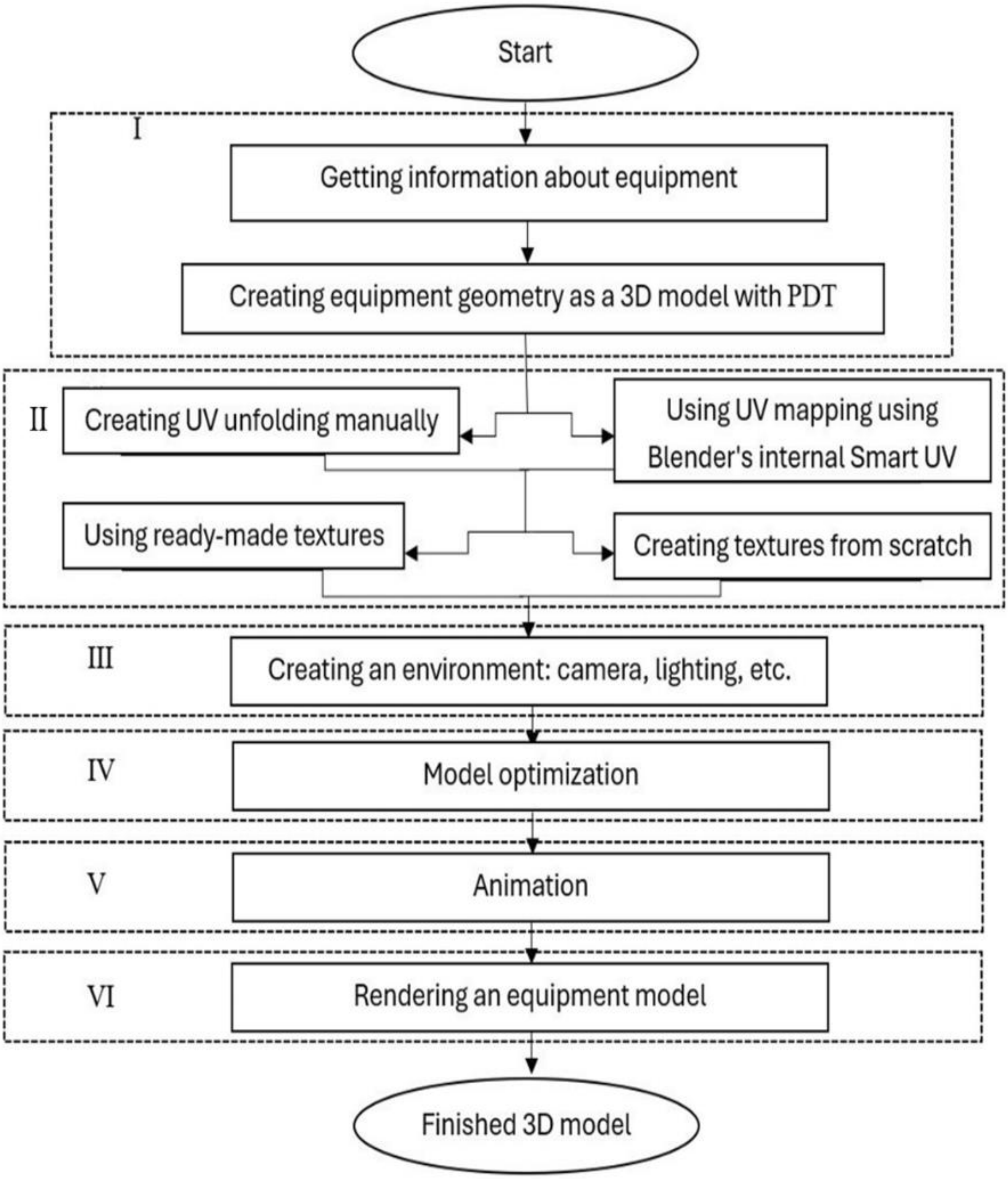

Figure 1.
Method of creating a 3D model of production equipment and infrastructure.

In the first stage of Figure 1, the object to be shaped is determined. For example, it can include production lines, mechanisms, machine tools, materials delivery systems, and the environment (building, lighting, ventilation systems, etc.). Initially, specific drawings or schematics of production equipment and infrastructure, as well as a plan of the production site, are utilized and analyzed. If possible, 3D scanning devices and the BIM (Building Information Modeling) model are employed. Using the information obtained, the steps for constructing the model are determined.

For this work, we took the technical specifications of the MMT-ST-1000 Chocolate Resting Stock Tank, which belongs to the Turkish company Memet Makina, from their official website [22]. The tank is used to move, stack, and store products such as butter, chocolate, cream, etc., at any time. It is available in different capacities to meet the needs of manufacturers who want to increase their productivity. The tank body design includes a heat jacket, a magnetic water level indicator, and a circulation pump for heating water. The tank mixer for 1000 kg periodically operates at a minimum speed of 24 rpm according to the set time, so the product structure does not deteriorate, and energy is saved.

Table 1.
Technical characteristics of tanks taken from the official website of the company.

Tank models	Capacity (kg)	Power	Mixing speed (rpm)	Width (mm)	Length (mm)	Height (mm)	Weight (kg)
MMT-ST-20	20	2.75 kW / 380 V	22.5	715	550	715	80
MMT-ST-100	100	5 kW / 380 V	18	785	750	1025	130
MMT-ST-250	250	5 kW / 380 V	18	1000	750	1250	220
MMT-ST-500	500	12 kW / 380 V	18	1250	915	1500	325
MMT-ST-1000	1000	12.5 kW / 380 V	24	1500	1165	1700	465
MMT-ST-2000	2000	12.5 kW / 380 V	24	1770	1400	1900	605
MMT-ST-3000	3000	13.5 kW / 380 V	22	1860	1500	2300	825

Judging by Table 1, the MMT-ST-1000 Chocolate Resting Stock Tank is designed for 1,000 kg of chocolate. The height of the tank is 1,700 mm, the width is 1,500 mm, and the length is 1,165 mm. We need this exact data to create a 3D model of the tank in the required dimensions. In addition, the reservoir diagrams were taken from the official website. As we can see from Figure 2, we have a side and top view with the exact dimensions of the equipment. The more accurate the scheme, the easier and more precise the 3D model will be. Therefore, all possible data was used to create a model of the equipment.

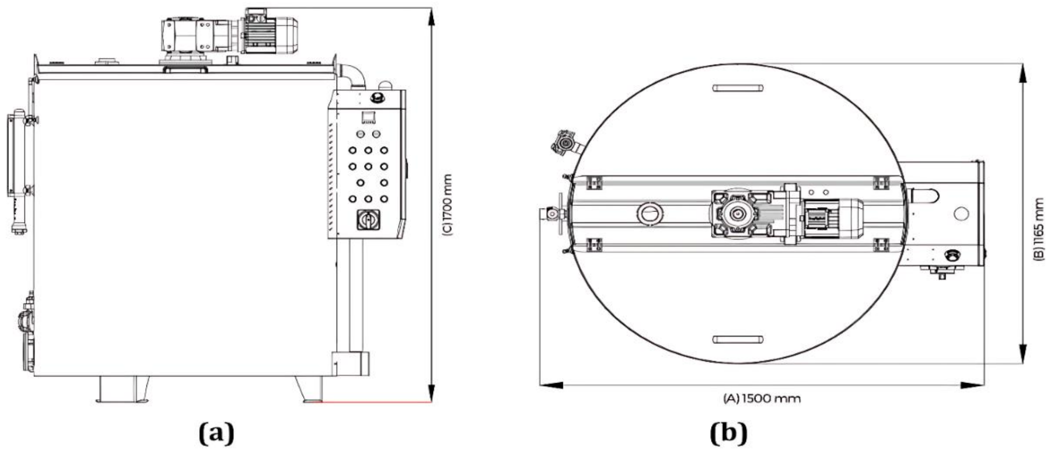

Figure 2.
Drawings of the MMT-ST-1000 tank: (a) Side view; (b) Top view [22].

Before we start working on the model, we need to integrate PDT, as shown in Figure 3. This integration will provide us with the ability to build a model with precise dimensions. Figure 4 illustrates the capabilities that PDT offers us.

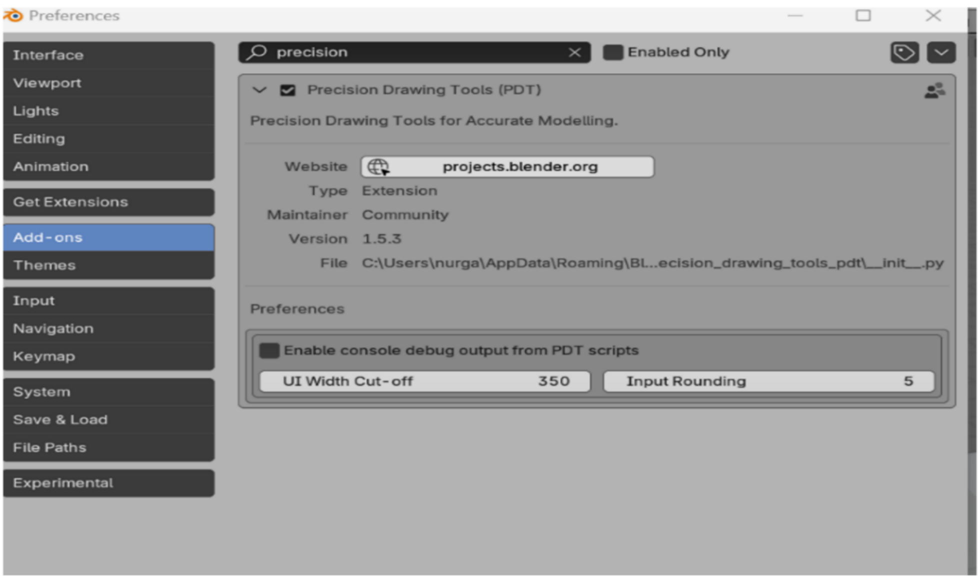

Figure 3.
Precision drawing tools integration.

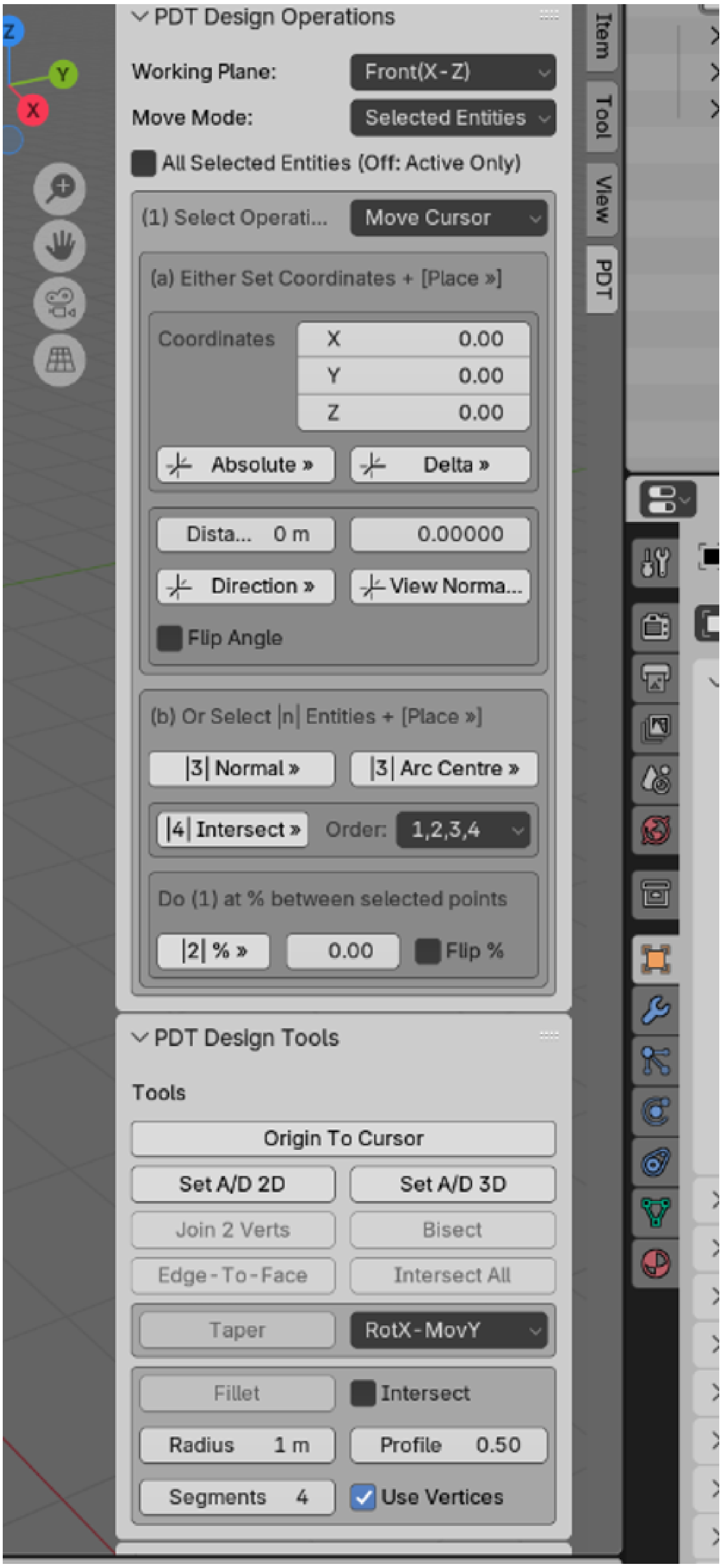

Figure 4.
PDT tools.

Next, creating the geometry of an object. To begin with, the basic shapes of the Blender program are used, i.e., elements such as a UV sphere, a cone, cubes, and a cylinder. Modifiers called Extrude, Bevel, and Loop Cut come into use to refine their geometry for the drawing of the production equipment or infrastructure to be created.

When creating the M model, the model is divided into small elements G_i (i is the object number), which are like the basic elements (G_{base}) of the Blender. It is described by the equation (1). The elements of the module undergo various deformations, during which geometric transformations such as rotation, scaling and shifting are used. Transformations of objects are described by matrices T.

$$G_i = T_{translate} \cdot T_{rotate} \cdot T_{scale} \cdot G_{base}, \qquad (1)$$

The finished m individual elements G_i of the module are connected to each other and described by a mathematical model (2) [23].

$$M = \bigcup_{i=1}^{m} G_i \qquad (2)$$

The figure below Figure 5 describes the matrix of the shift, rotation and scaling model.

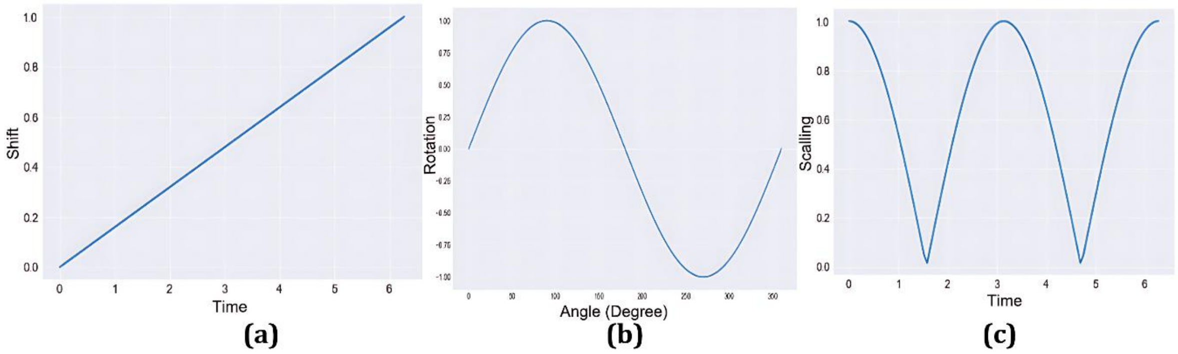

Figure 5.
Basic geometric transformations: (a) time-dependent shift; (b) rotation depending on the angle of rotation; (c) scaling depending on time.

Figure 6 shows that a cylinder is used to create the main part of the tank. The diagram shown in Figure 2 is used as a background drawing. The model will be made according to this drawing.

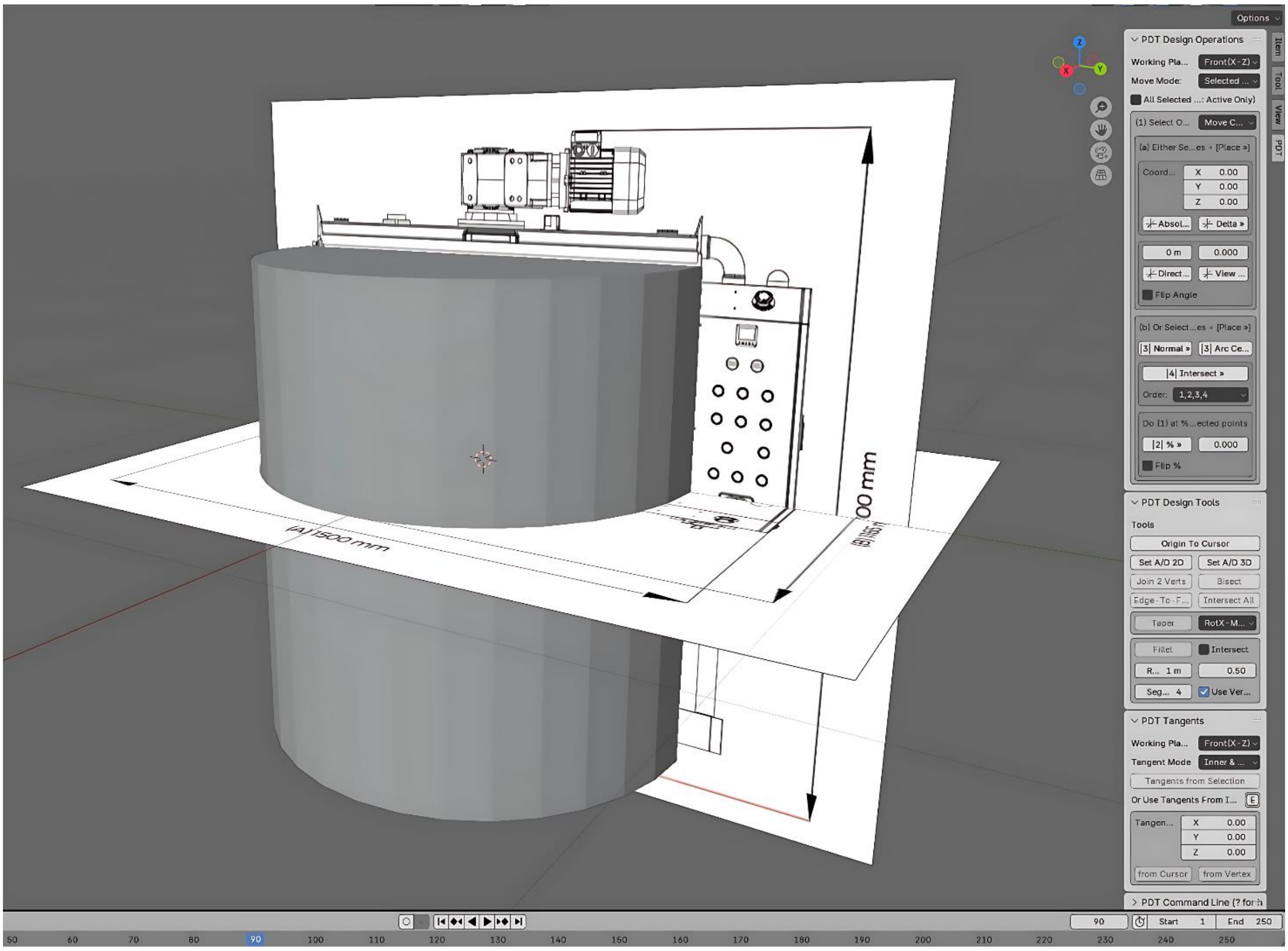

Figure 6.
Creation of the main part of the tank.

For detailed modeling of the model, various brushes are used, such as pulling, smoothing, and deforming in the sculpting section. It is especially important to model not only large elements of equipment but also small parts, such as bolts, fasteners, electrical wiring, and pipes. This is necessary to demonstrate the infrastructure accurately and truthfully. In principle, it is advisable to create each detail separately and then import everything in one place, considering the scale.

For the digital twin, it is necessary to consider the specific dimensions of production equipment and infrastructure facilities. Blender allows us to adjust the measurement system to meters or millimeters, ensuring compliance with proportions. It is also possible to import objects at the desired scale. The equipment can consist of many repeating parts (for example, conveyor belts or machine tools), creating variations of the model's repeating parts (depending on size and turning surface) using arrays, without having to recreate the shape repeatedly.

In Figure 7, an array is used to avoid repeating this piece of equipment.

Figure 7.
Using an array for a tank part.

In Figure 8, the finished elements were imported into the main object and combined into one model. The result was a tank model.

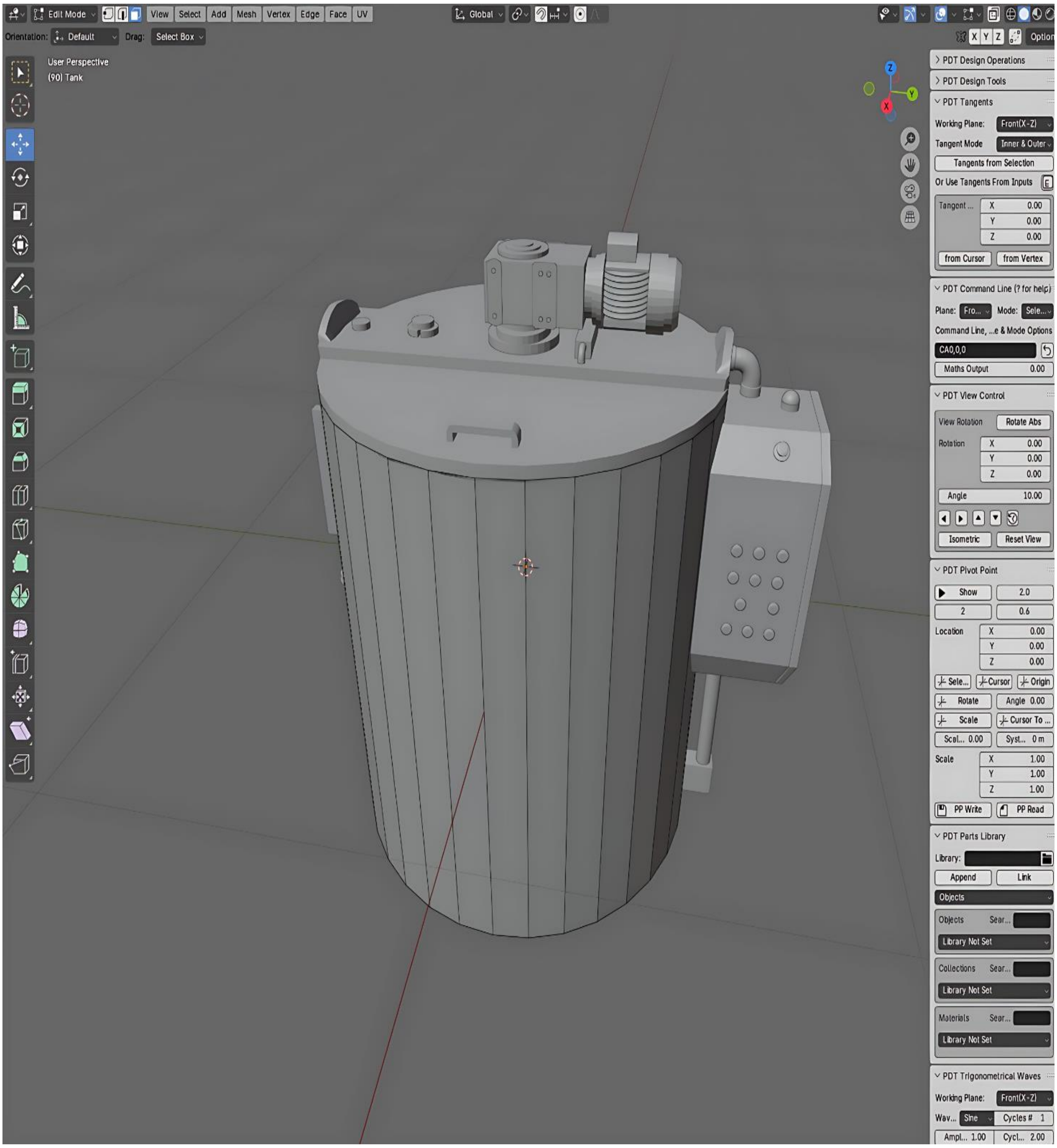

Figure 8.
The finished model of the equipment after importing all the parts.

The second stage involves adding texture to the model and working with the materials used. Texture is one of the main elements of 3D modeling, visually imparting certain properties to the model. Before applying texture to the model, a UV map is created.

The UV linear sheet of the model is created so that the texture is accurately positioned on the model. To simplify the work of the developer, the Blender device has a Smart UV prediction function. This function automatically cuts the UV linear sheet of any shape by itself. The developer will save it as an image only and match the texture to this linear sheet, as shown in Figure 9.

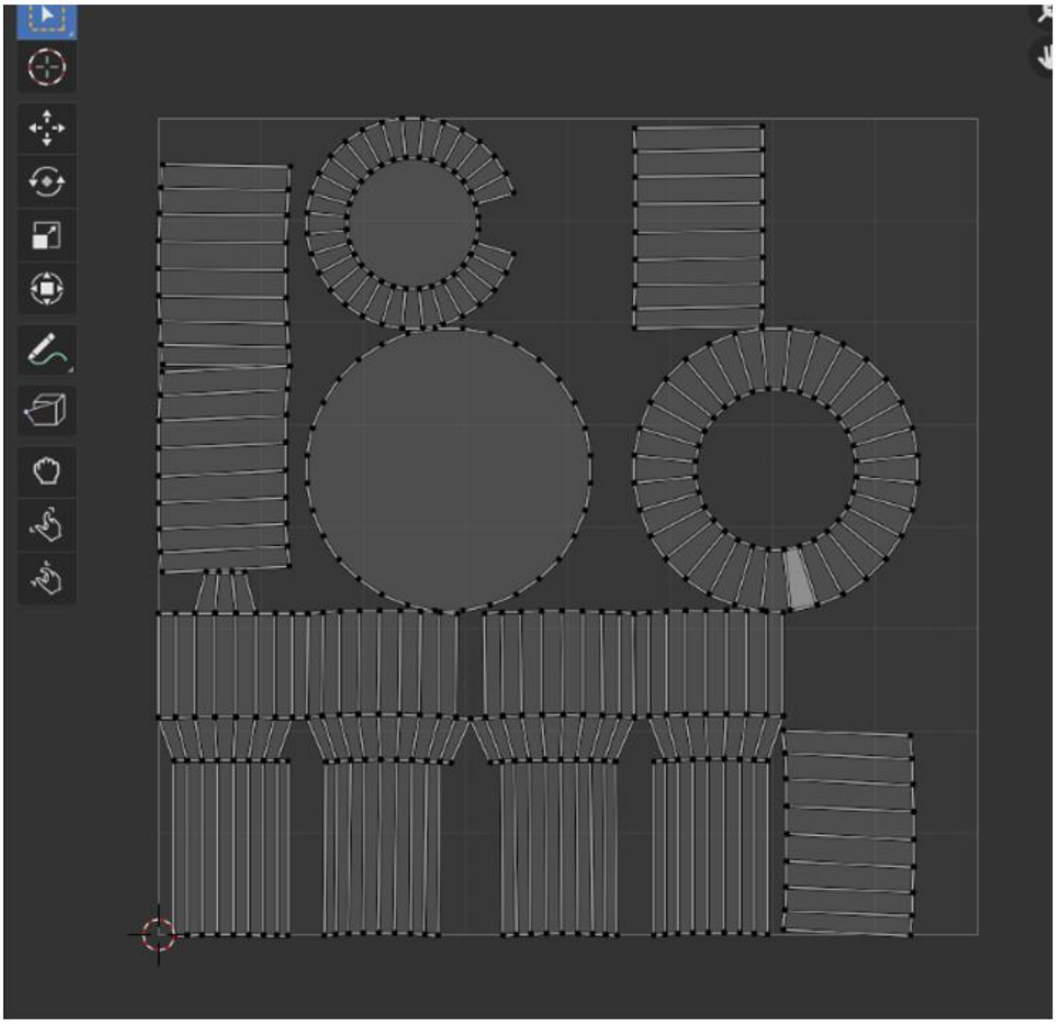

Figure 9.
Applying texture to UV linear sheet of production equipment.

As a rule, a certain image is placed on the form to give it texture. In Blender, PBR (Physically Based Rendering) materials can be used to create true reflections, iron, plastic, and other materials. In principle, Blender can give texture to the model in two diverse ways. The first is the use of ready-made textures. The second is to manually create a new texture. In other words, each visually visible roughness, point, color, glow, and other visual effects are used to create individual maps in a new way. As shown in Figure 10, the texture is created by developing a scheme in the shading section.

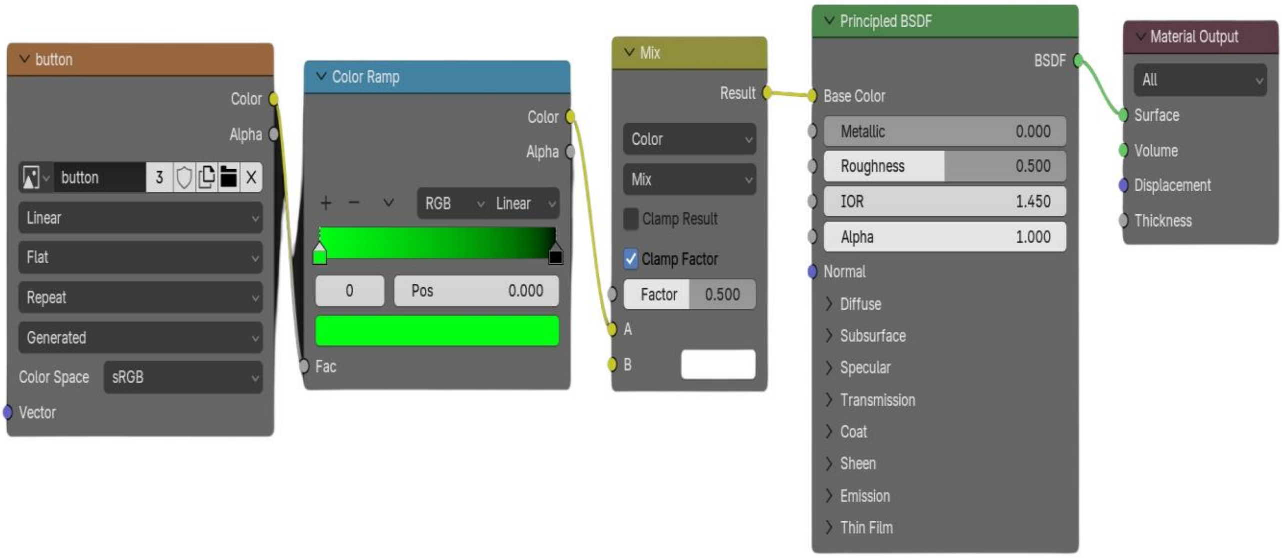

Figure 10.
Texture creation scheme.

The first block specifies the UV scan to use. The second block specifies the main color of the model. The third block mixes the color of the main model with an additional color. The next block specifies metallicity, roughness, refractive index, etc. The last block is needed to output the finished texture to the model.

The third stage is modeling the environment. For the digital twin to be more realistic, and not have a blank black background, the infrastructure must be shaped on the stage; that is, the location of the equipment (for example, the production facility) is depicted. For the equipment to be visualized realistically, external forces such as wind, gravity, etc., are utilized. Light sources are necessarily placed on the stage where the equipment is located. If necessary, we can enhance the realism of the production room by depicting environmental influences such as dust, steam, and smoke. Such phenomena are created using the Volumetric Effects method. In Figure 11, we created a room for equipment and a table. We also added lighting and a camera. For convenient viewing of the model, we switched the viewing to the shading type in the viewport.

Figure 11.
Creating a model environment.

Lighting is one of the main elements in rendering, so it is necessary to consider the different types of light and how lighting affects the appearance of the model. For this purpose, the Phong lighting mathematical model (3) is used.

$$I = I_a k_a + I_d + I_d\big(k_d(N \cdot L)\big) + I_s k_s (R \cdot V)^n, \qquad (3)$$

Here:
I – the intensity of the light, which determines the brightness of a point on the surface.
Indexes a, d, s – designations for ambient, diffuse and specular light.
k – the surface-to-light ratio.

N – normal to the surface.
L – the direction of the light source.
R – the direction of the reflected light.
V – the direction of the camera.

n – an indicator of the degree that determines the sharpness of the glare.

I_a, k_a– ambient Illumination, which describes the uniform distribution of ambient lighting, including lighting reflected from objects. Because of this, objects that are in shadow are not simply colored black.

$I_d, k_d(N \cdot L)$ – diffuse lighting. This is lighting that shows light that is scattered in all directions depending on how the object is turned towards the light source. It is based on Lambert's law, which says that the angle between the direction of light and the normal affects the brightness of light. This law is described by the scalar product N·L. The smaller the angle, the brighter the light will be.

$I_s, k_s(R \cdot V)^n$– specular lighting. This lighting describes the properties of the object's material, due to glare and reflection. The scalar product R·V describes the brightness of the glare as a function of the reflection distance to the camera [24].

Figure 12 describes the dependence of light intensity on the angle of incidence of light. As we can see, ambient light does not depend on the angle in any way, while diffusive and specular light depend on the angle in opposite ways.

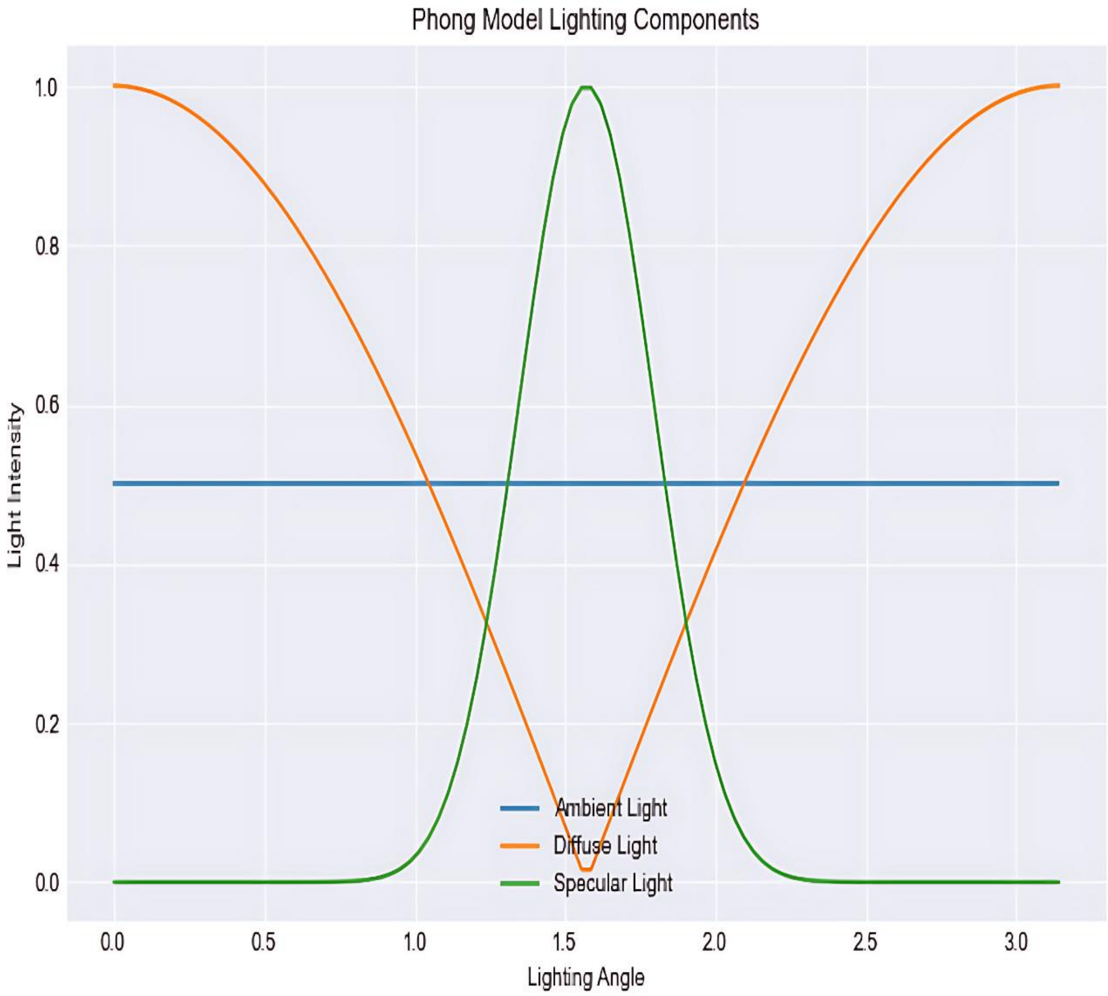

Figure 12.
Plot of the components of the Phong lighting model.

In a ready-made model of equipment, the number of points may be too large, making collaboration difficult at the fourth stage. To enhance the performance of rendering and animation processes, it is advisable to optimize the model. To reduce the number of points in the modifier section, subsections are removed in the multi-resolution modifier, and nearby points are combined using the simplification modifier.

In Figure 13, we utilize the multiresolution and simplification modifiers to optimize the model.

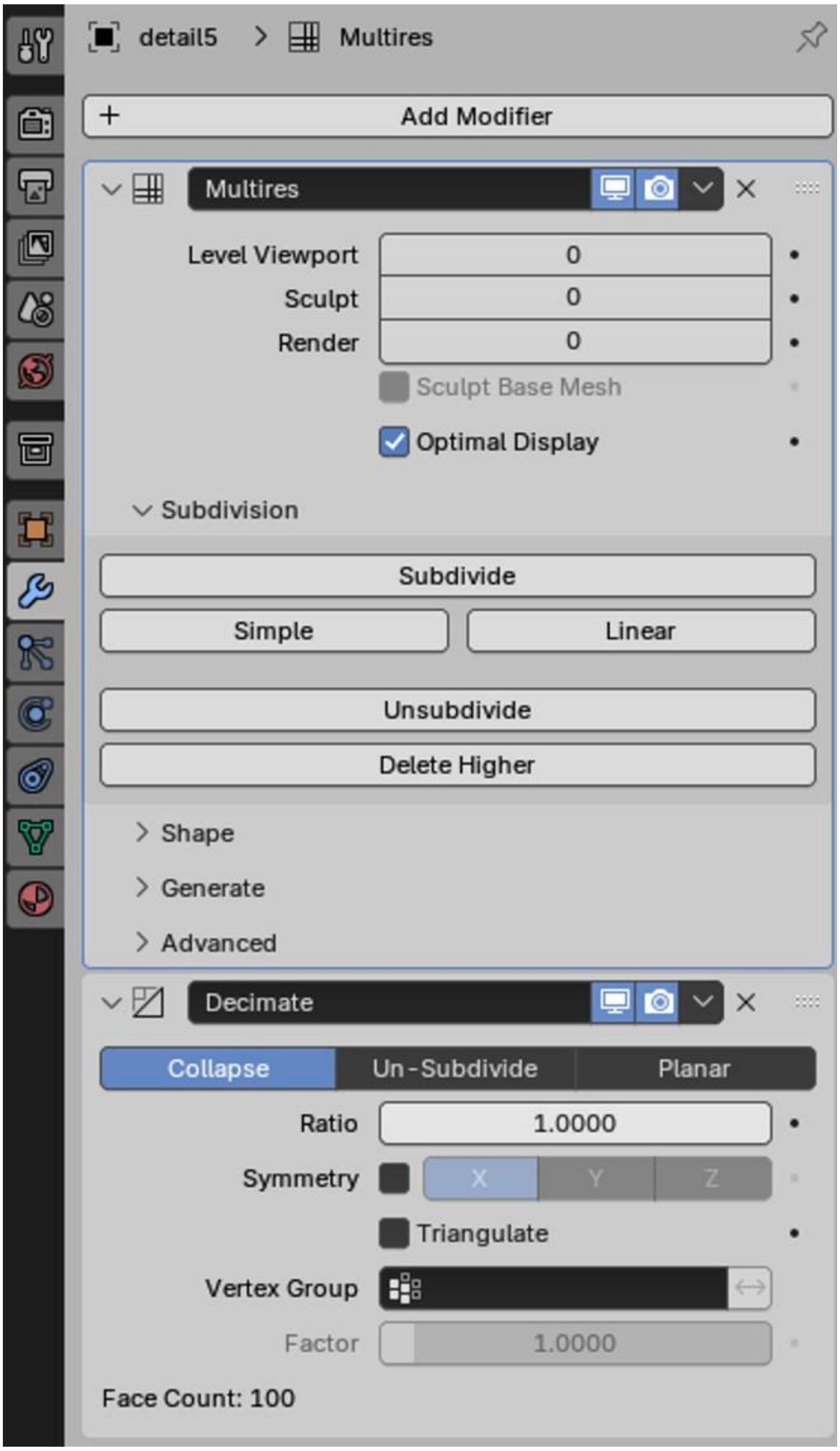

Figure 13.
Optimization modifiers.

The fourth stage is the optimization stage. In addition, in the edit section, we need to select all the points of the model, and in the mesh section, click on the button labeled "Geometry," which says "Delete." At this point, the "Simplify Geometry" window will appear on the left side of the screen. As shown in Figure 14, the geometry of the equipment is optimized by entering the exact percentage by which the shape should be simplified in the ratio line.

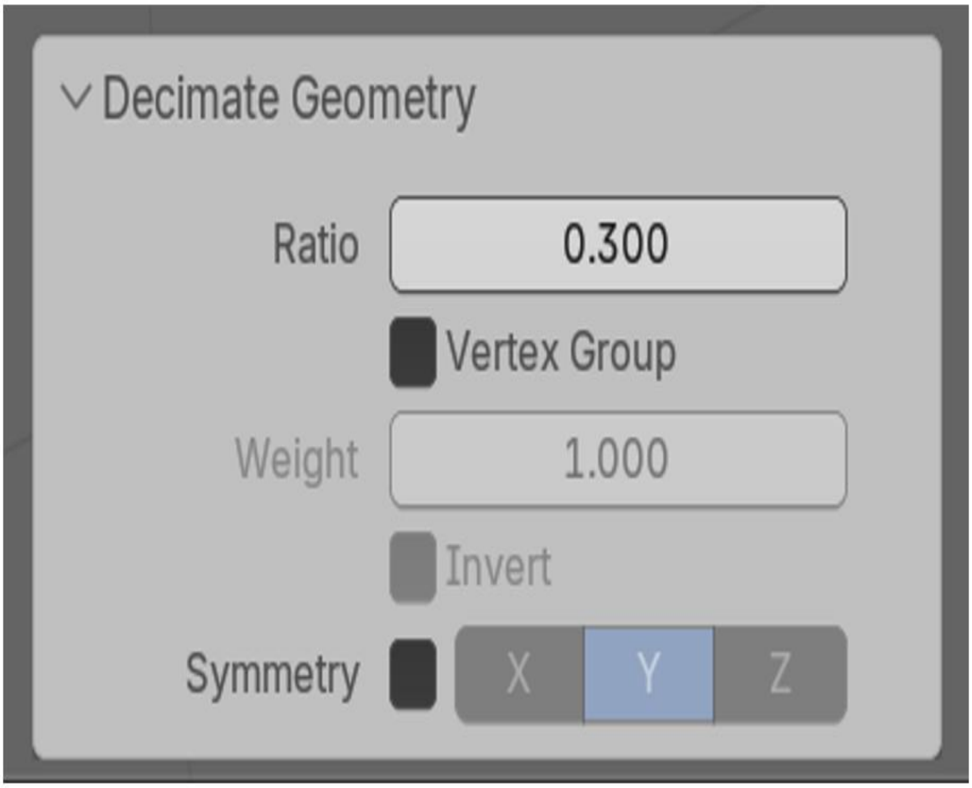

Figure 14.
Geometry simplification function.

The optimization approaches allow us to reduce the number of points without losing the quality of the model.

When optimizing the object G_i, the model may lose accuracy due to a decrease in the number of vertices and surfaces compared to the real object $G_{real,i}$. However, errors between the real object and the 3D model must be minimized. This can be described by the following mathematical model (4) [23, 25]:

$$\min_{M} \sum_{l=1}^{m} \left\| G_i - G_{real,i} \right\|. \quad (4)$$

The fifth stage is the animation stage. If the molded equipment has parts, then rigging (creating a skeleton) can revive those parts. In Blender, moving particles associated with each other can be connected using the Inverse Kinematics function, simplifying the animation process. For example, with the use of this function, the movement of gears is optimized. Keys are placed in the timeline so that each movement of the equipment is saved as a frame.

Digital twins help with control, diagnostics, and forecasting, which leads to the optimization of the operation of real objects. For this reason, the models created must be visualized in real-time. The shapes created using Blender can be applied in real-time using the Eevee rendering engine. This allows us to effectively achieve high-quality visualization [26]. Therefore, stage 6 of figure 1 is rendering. In addition, ready-made hardware models can be exported in OBJ, glTF, or FBX formats and embedded in other platforms that can operate in virtual environments or augmented reality systems (AR), such as Unity or Unreal Engine. This will be useful for the interactive management of production services.

When modeling, it is important to consider the time *T(M)* and costs *C(M)* that were spent on creating each complete model. In real-world conditions, there are cost C_{max} and time T_{max} constraints. Therefore, the following inequality (5) is appropriate.

$$T(M) \le Tmax \ , C(M) \le Cmax \ , \quad (5)$$

$$Q(M) = g(M) - \alpha T(M) - \beta C(M), \quad (6)$$

$$\max_{M} Q(M) = g(M) - \alpha T(M) - \beta C(M). \quad (7)$$

The quality assessment Q(M) of the model is determined by formula (6), where α and β are coefficients reflecting the influence of time and costs, and the initial quality, which is the best. To calculate the maximum quality with the given constraints (5), equation (6) is maximized, resulting in model (7) [27].

As we can see in Figure 15, given the constraints of cost and time, it is possible to identify the model with the best quality at the lowest possible cost and time.

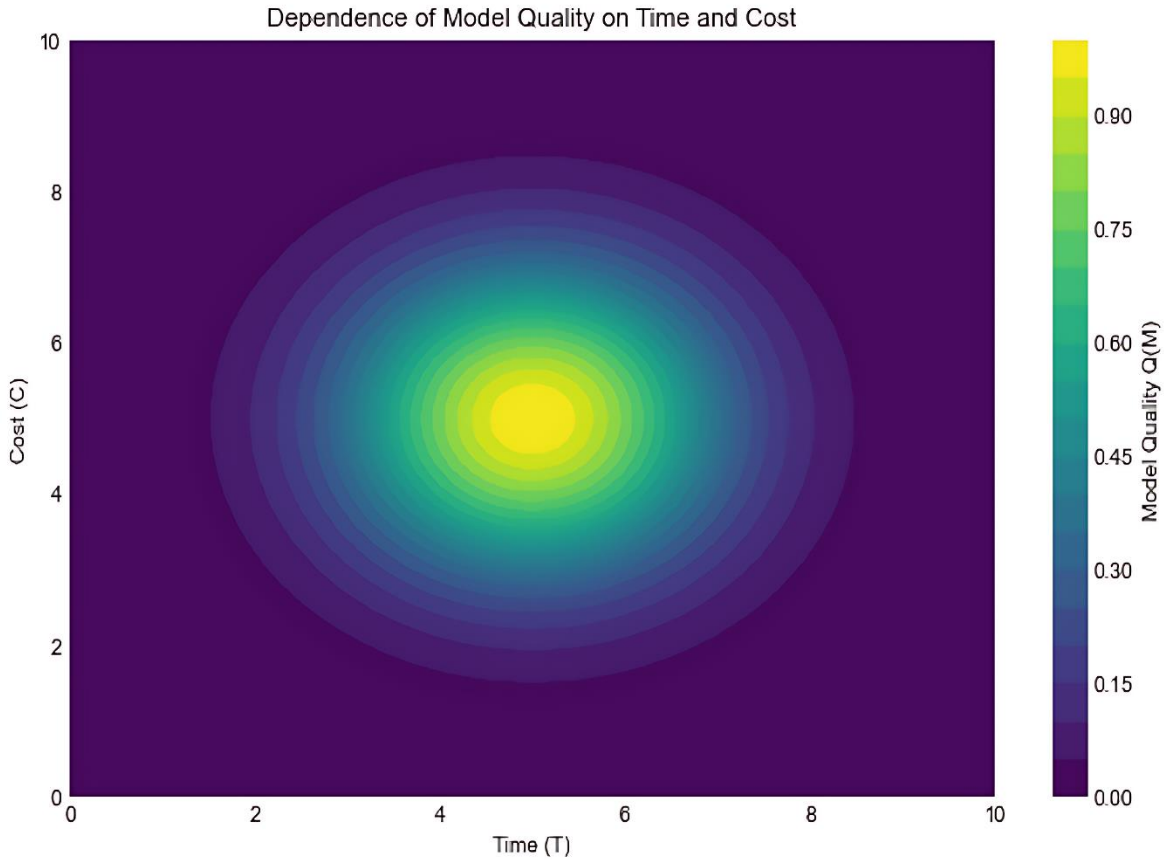

Figure 15.
Dependence of model quality on time and cost in the presence of constraints.

After all the above processes are considered, the model is evaluated. The very first test is to check the accuracy of the data. It includes the size of production equipment and infrastructure, the realism of textures, and the correctness of animation. The next type of testing is verification using real data. The Internet of Things (IoT) sends the true data coming from the sensors to the created model, and the feedback is analyzed. After the digital twin has successfully passed all tests, employees in this production should be trained to work with 3D equipment models in a safe virtual environment.

In Figure 16, we have rendered the model from the camera using the Eevee rendering engine. Light, shadows, and highlights are taken into account here.

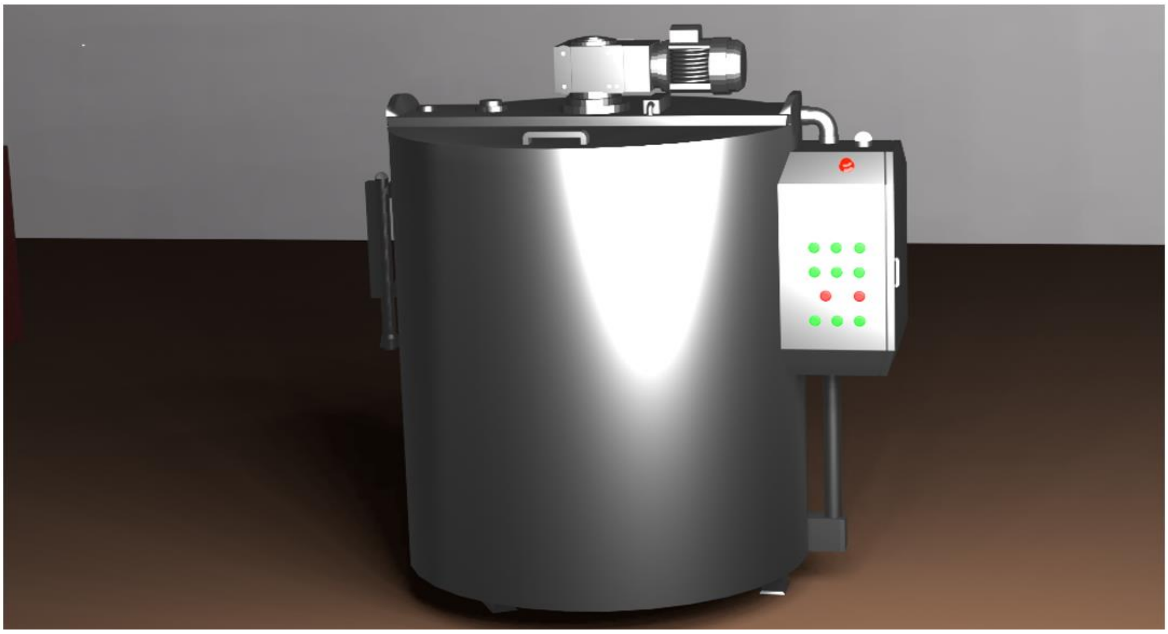

Figure 16.
3D model of the MT-ST-1000 chocolate resting stock tank.

Figure 17 illustrates the relationship between the power used and the volume of the tank. The smaller the volume, the more power is required for storing and mixing products.

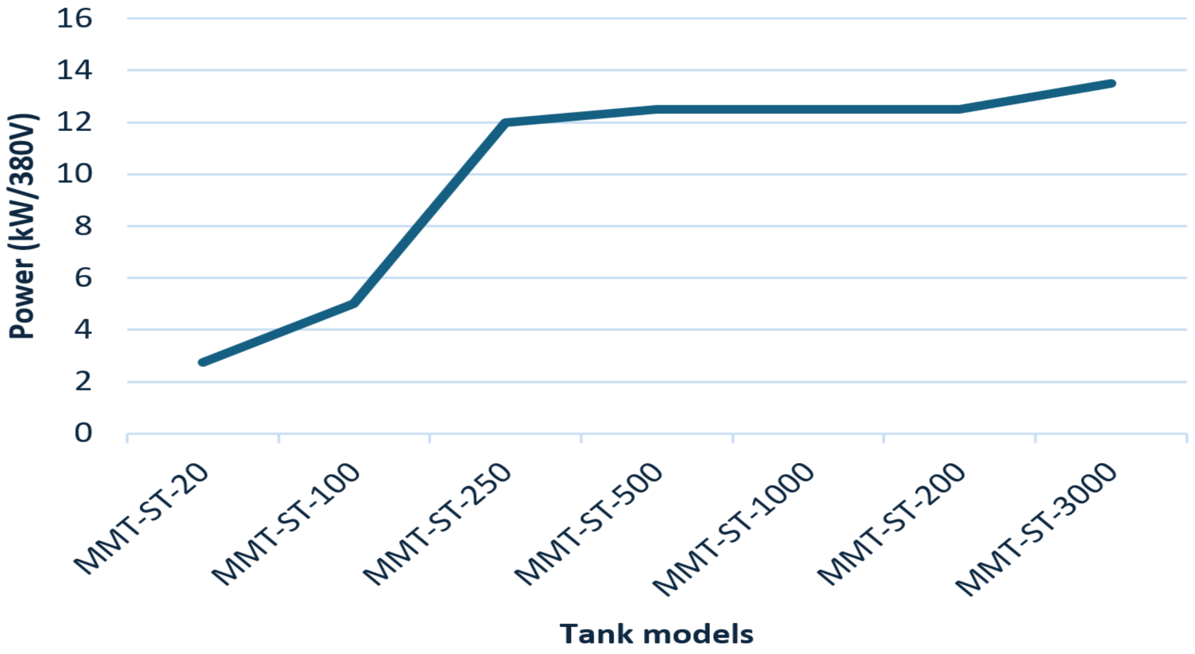

Figure 17.
Power of different types of resting stock tank.

Figure 18 describes the dependence of the mixing speed on the tank model. Judging by the graph, the mixing speed is in the range of 18 to 24, with an average of 21.

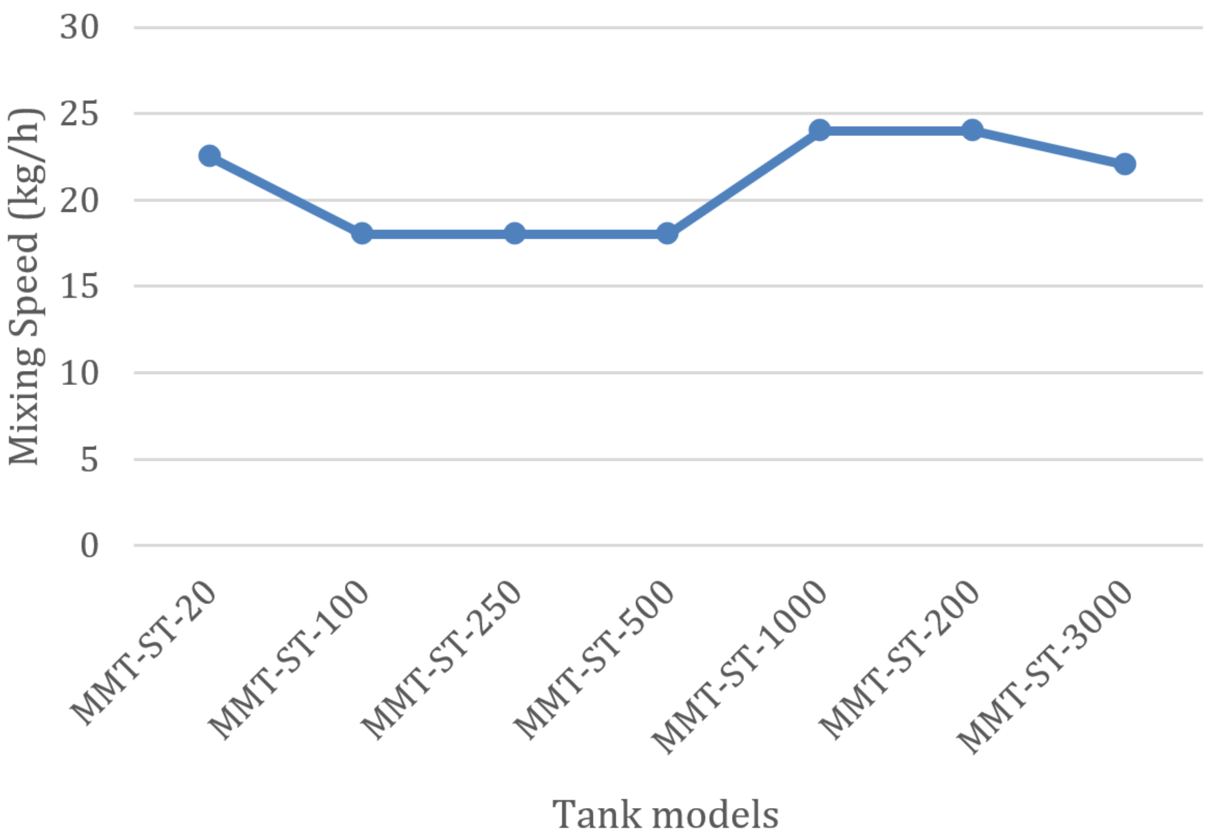

Figure 18.
Mixing speed of different types of stock tank.

4. Discussion

In this paper, an algorithm for creating 3D models of production equipment and infrastructure for a digital twin was considered. To identify the features of the selected program, we took the article "Design of Digital Twin System for Harbor Cranes Based on Unity 3D" [28] and the article "Discuss the Application and Presentation of 3D Visualization Technology in Data Center" [29] for comparison, where 3ds Max and SolidWorks are used as tools for 3D modeling. We concluded that the advantage of our work is that we used Blender as a tool for creating a 3D model to develop a digital twin. The fact is that 3ds Max and SolidWorks are limited in their functionalities. In addition, both are paid software, while Blender is free and provides comprehensive 3D modeling, including texturing and animation capabilities, making it an affordable solution for enterprises. Blender has many functions not available in those programs, and the models look more realistic.

Table 2.
Comparison of Blender, 3ds Max, and SolidWorks.

Parameter	Blender	3ds Max	SolidWorks
Price	$0	$1,545 (first year)	$3,995 (basic version)
Supported formats	25+ (e.g., FBX, OBJ)	30+ (e.g., DWG, FBX)	10+ (e.g., STEP, IGES)
Time for training (hours)	50-100	30-50	40-80
Rendering (FPS)	30-60 (depending on scene)	25-50 (high quality)	10-20 (CAD visualization)
Performance (by number of polygons)	1,000,000+ (depending on system)	500,000+ (depending on system)	200,000+ (depending on system)
GPU rendering support	Cycles and Eevee support for GPU rendering, fast real-time rendering	GPU rendering support, but with more complex setup	Rendering is limited, not designed to work with GPU rendering
Scripting and automation support	Full Python support for process automation	Python support for scripting, but less flexibility than Blender	Limited automation, macro support, but limited flexibility for animations and visualizations
Support for extensions and plugins	Many free and paid plugins created by the community. Including the add-on PDT	Many plugins, many paid and professional	Limited plugin support, most extensions for engineering tasks
Support for CAD	Limited. However, thanks to an add-on like PDT, we can use more of the CAD functions	No	Full
Applicability to a digital twin project	High: General-purpose tool for visualization, simulation, and integration with real-time systems	Moderate: Powerful for visualizations but requires customization for real-time simulations	Limited: Accurate engineering models, but difficult to integrate for a digital twin

For a more detailed comparison of Blender, 3ds Max, and SolidWorks in the context of creating a 3D model of a food enterprise for a digital twin, we have prepared Table 2 with data on key aspects using information from their official websites [30-32]. The last point, "Applicability to a digital twin project," serves as a conclusion regarding the feasibility of using these tools for the purposes of a digital twin.

5. Conclusion

The Blender device makes a significant contribution to the creation of a digital twin of industrial equipment and infrastructure. This equipment not only facilitates the creation of a 3D shape but also enhances it with animation, textures, external forces, and production effects. The models built in Blender aim to display, manage, optimize, and predict production processes in high quality, ensuring effective interaction with the real environment and real-time through the integration of the Internet of Things and augmented reality systems.

In this paper, the contribution of the Blender device to the creation of a 3D form and a digital twin of production equipment and infrastructure is considered. In particular:

1) The process of forming a model using PDT is described in detail. The properties of sculpting and CAD using PDT are utilized, and detailing is provided using various handles.

2) All the created objects were given texture, and the drawing of the UV linear sheet of the model was displayed.

3) In order to reduce the size of the drawn model, the possibilities for optimization were discussed.

4) The importance of the production environment, in addition to the equipment for creating a virtual environment, was considered.

5) The animation process and rigging properties were defined to give the model dynamics.

6) The possibilities of rendering ready-made forms have been identified.

In addition, mathematical models of various aspects such as object optimization, geometric transformation of an object, and Phong lighting components were considered. Graphs were constructed to visualize these mathematical models. The advantages of Blender compared to other 3D modeling tools, such as SolidWorks and 3Ds Max, were discussed in detail. As we found out, Blender is a free 3D modeling tool that can utilize additional add-ons such as PDT. Thanks to this feature, Blender can gain the ability to work with the functions of other 3D tools, such as CAD. This tool is also convenient for exporting to other platforms and rendering at high quality. These advantages provide us with the opportunity to use Blender to create 3D models of production equipment and infrastructure for a digital twin of an enterprise. The process of creating 3D models is very long and complex, so future research will consider 3D modeling tools that use AI and machine learning to create a digital twin to optimize the 3D model building process.

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