

The Application of Digital Twin in Design

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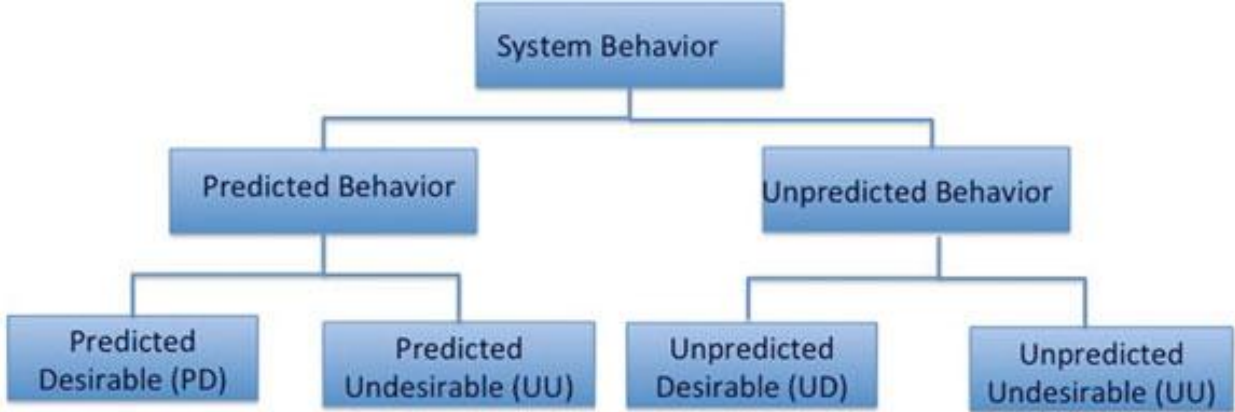
ABSTRACT

Digital media, as an efficient means of conveying and preserving information for humans, has rapidly expanded its application beyond industrial automation due to the highly interconnected nature of content. This paper aims to investigate the utilization of product design methods in industrial projects by employing digital twins as carriers to achieve the presentation aspect of digital twin projects. By analyzing the design requirements of industrial projects and the development trends of digital twin technology, a proposed scheme is presented for applying product design based on digital twin technology. The article emphasizes on integrating construction methods and design approaches within the digital twin system, as well as operational techniques and inspiration for visual end product design, in order to effectively utilize this tool - digital twins.

Keywords: Digital twin technology, industrial design, design research.

COLLABORATIVE DESIGN IN DIGITAL TWINNING

The earliest research on digital twin technology appeared in the late 20th century, and was proposed as a sustainable multi-engineering technology integration scheme applied in the aerospace field. Michael Grieves Having a pivotal influence in this field, he clearly pointed out the definition and composition of the digital twin software technology in his article, for example, he proposed "the idea of a digital twin is to be able to design, test, manufacture and use virtual versions of a system. We need to know if our design can actually be manufactured. We need to determine the failure mode of the system in use. We need all this information before a physical system can actually be created. This will reduce failures of physical systems during deployment and use, reduce expense and time, and most importantly, reduce harm to users."



Source: Grieves, M., & Vickers, J. (2016). Digital Twin Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems.

Figure 1: Categories of system behavior

And research with NASA shows the importance of product lifecycle management in the digital twin to provide safe, reliable, and affordable solutions for the overall strategy of space exploration. These will improve the ability of industrial engineering projects to utilize scarce resources and win the trust and understanding of customers. The digitization of physical objects, the digitization of their behavior and characteristic mechanisms, as well as the digitization of dynamic detection and status data, are the prominent features of digital twins. The design process for digital twin products involves collecting all relevant variables, synthesizing experience and data, and transforming design elements through a process that

includes concretization, differentiation, standardization, and datafication. This results in reliable examples for static digital twins and captures parameters for dynamic digital twins. Innovative designs in intelligent manufacturing face the rapid development of the informatized manufacturing industry. Tianwei Shao et al. propose that multiple design entities should collaborate to achieve unified design goals through information exchange and specific collaborative mechanisms. This is necessary to meet market demands that cannot be fulfilled by individual product designs alone. From a technical perspective, their team simplifies digital designs based on model-based design (MBD) by eliminating redundant information from different modeling languages used by various departments within a unified enterprise during production processes. They also remove changes made in response to user requirements which would otherwise increase project complexity. Furthermore, they emphasize key aspects of system-oriented manufacturing using digital twin technology: (1) The digital twin body serves as a simulation model representing a product throughout its lifecycle with integrated data management capabilities. (2) Real-time exchange and mutual improvement between data/information from the digital twin model and physical entity. (3) Accurate digitized description of physical entities using the digital twin model. (4) Utilizing the digital twin model for simulating, predicting, monitoring, and diagnosing physical processes.

APPLICATION OF DIGITAL TWIN MODEL IN MANUFACTURING

For some of the key technologies in digital twin applications, many researchers and engineers work in teams around specific projects.

Computer Aided Design in Dynamic Modeling and Model Driven Technology

Haiying Song et al.(2024) discussed how to use digital twin software Tecnomatix to research and develop intelligent production lines, and use Tecnomatix software to conduct offline programming and action simulation of robot units in the developed production line, and further optimize the movement path of robots. It is proved that the digital twin design technology can not only train the robot offline programming ability of automation technicians, design the best process of automatic production line driven by control logic events, but also realize the overall planning and local debugging of intelligent production line.

Monitoring, Evaluation and Control Optimization of Intelligent Manufacturing System

Dongyang Han , XIA Tangbin, et al.(2024) In the forward direction, the data mapping twin entity provides monitoring services, and in the reverse simulation control optimizes the physical entity behavior to complete feedback, so as to realize the full closed-loop control of the manufacturing process. Methods A multi-layer architecture corresponding to the five-dimensional model was built by connecting physical real data and twin virtual data in the information physical system. A multi-scale and multi-level twin modeling method is designed, which combines model definition and finite state machine technology to build twin scenes of physical properties and action behaviors on Unreal Engine. By integrating artificial intelligence and behavior simulation model, the simulation behavior is generated to control the processing process, and a platform is built for the intelligent manufacturing system of assembly parts, and the model maturity and twin reliability are verified.

The Virtual Model Feeds Back to The Physical Model

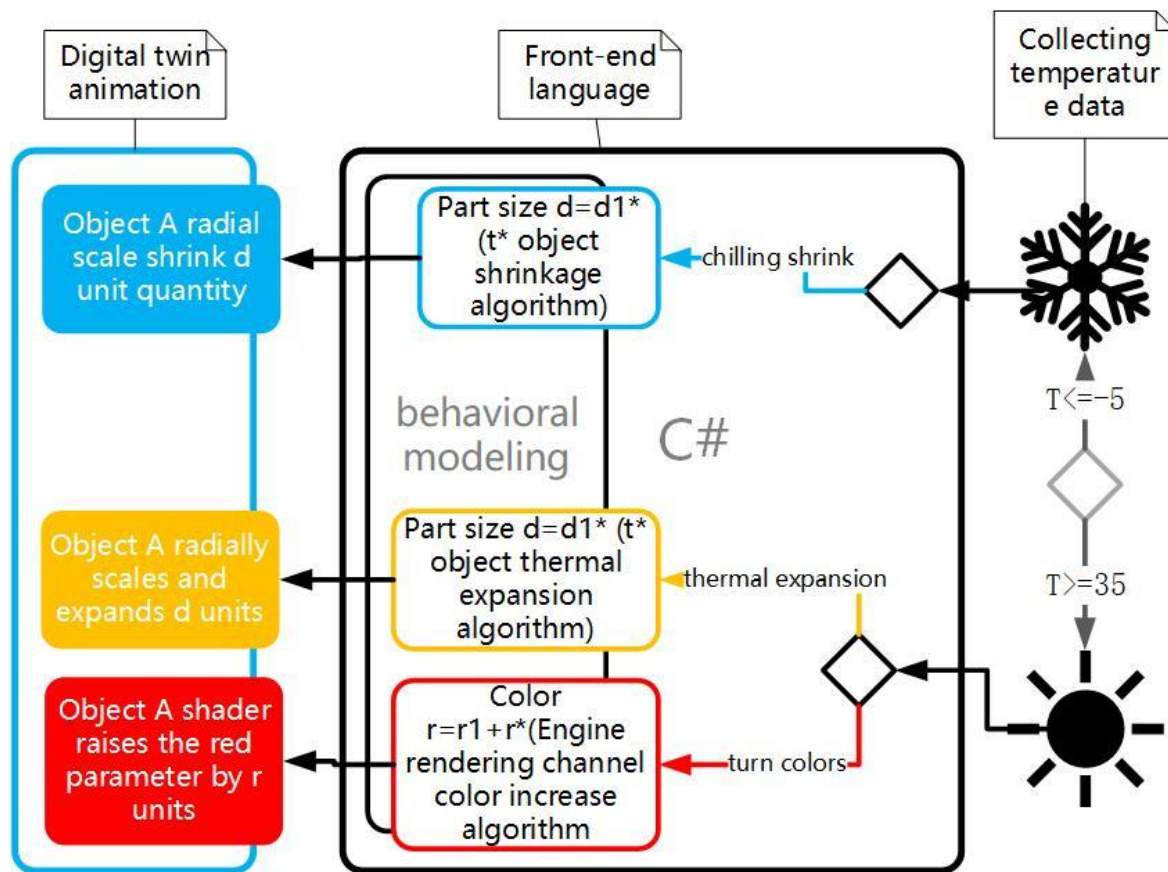
Xudong Zhang et al.(2024) focus on the problem of insufficient response of the digital end to the real situation of the physical end in the research of the digital twin system of cartesian robots. Based on the method of combining external vision and digital twin system model, the digital end model is established based on semi-physical simulation technology, and the digital twin system of cartesian coordinate robot is constructed. The digital twin system model combined with external vision is designed, and the key technologies involved in the construction of digital twin system are analyzed, including digital end model, controller and external vision monitoring realization The digital twin system of cartesian coordinate robot is developed and the related functions are realized.

COMPUTER LANGUAGE IN DIGITAL TWINS

This article is based on the Unity virtual engine and the corresponding modeling language C#, summarizing and summarizing the design methods of the front-end display of digital twin projects. UML (Unified Modeling Language) and sysML (System Modeling Language) are algorithmic and mathematical modeling collections in digital twins, which are also the core of digital twin data calculation, and they are one level higher than script algorithms built based on virtual engines. At the information level, they are also object-oriented languages that evolve and change according to different physical objects of twin clients. Directly referencing object-oriented languages in script algorithms greatly reduces the difficulty of digital modeling and simulation work. MBD (Model Based Definition) based on entity modeling is a major component of visualizing digital twins, playing a role as C# modeling language in virtual engines, involving geometric, behavioral, contextual aspects, etc., for virtual object modeling. By reverse engineering the construction program for digital twins can we obtain that event behavior in a digital twin animation comes from behavior modeling process(Guochen.Li,2020).

TRANSLATION OF DIGITAL TWIN DATA IN DESIGN

Figure 2 shows an example that illustrates how the construction process of a digital twin project is like an experimental research platform continuously evolving to produce qualitative products by designers.



Source: This study.

Figure 2: Reverse translation of the animation model

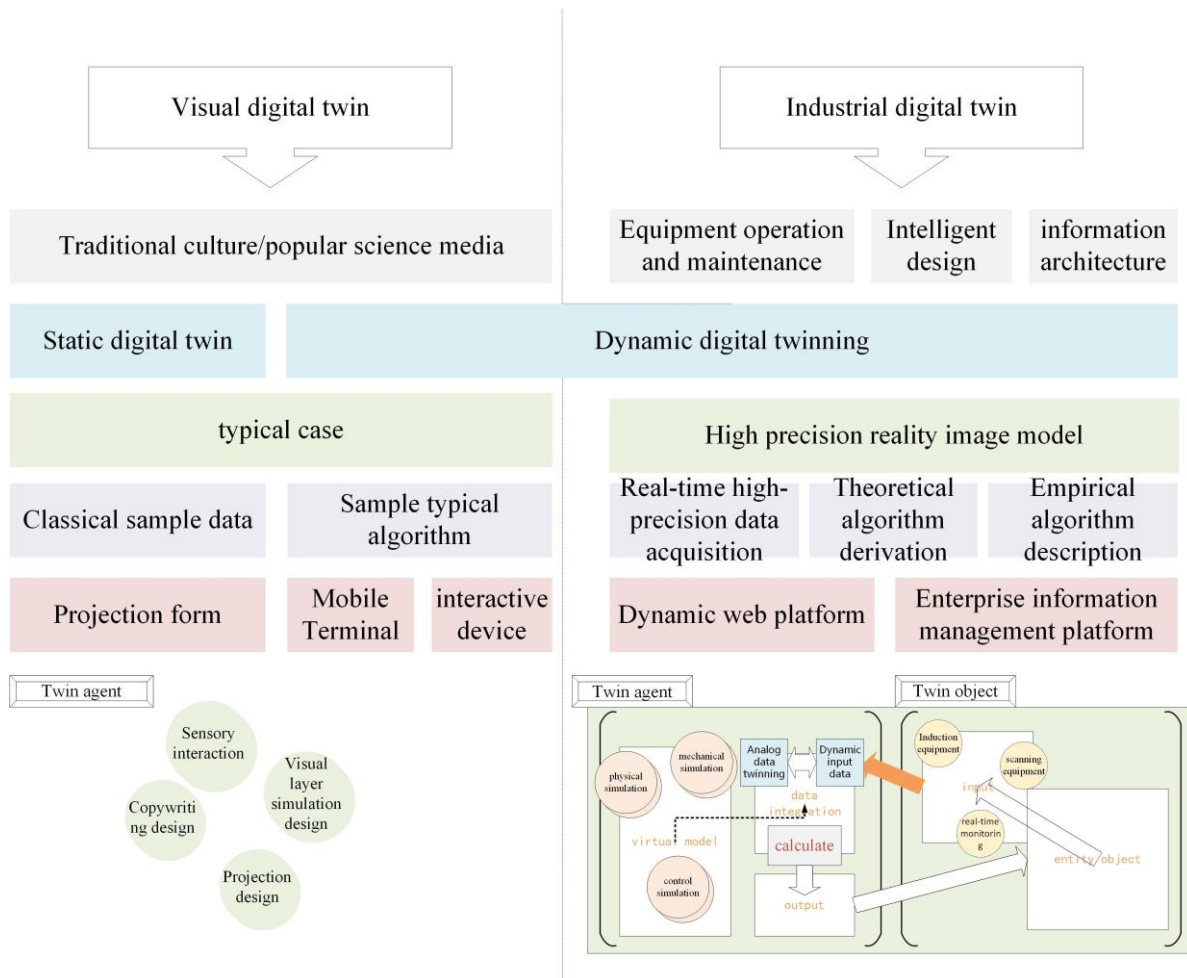
APPLICATION OF DESIGN METHOD IN DIGITAL TWIN PROJECT

However, products produced from this process are constantly changing due to various factors such as environmental factors, human factors, and product's own operating cycle influences. In addition to this aspect, digital twins also present data changes during their operating cycles through information feedback to users objectively summarize regular trends in order to help product iteration updates; at same time, it has positive significance for users actively avoiding unfavorable factors for efficient continuous operation or proactively changing application plans.

THE STRUCTURE DIVISION OF DIGITAL TWINS AND THE APPLICATION METHOD OF FRONT-END DESIGN

Structure Division of Digital Twins

Figure 3 divides the structure of digital twin technology from five perspectives: application field, application purpose, twin object, twin data type, twin data type and visual interactive terminal.

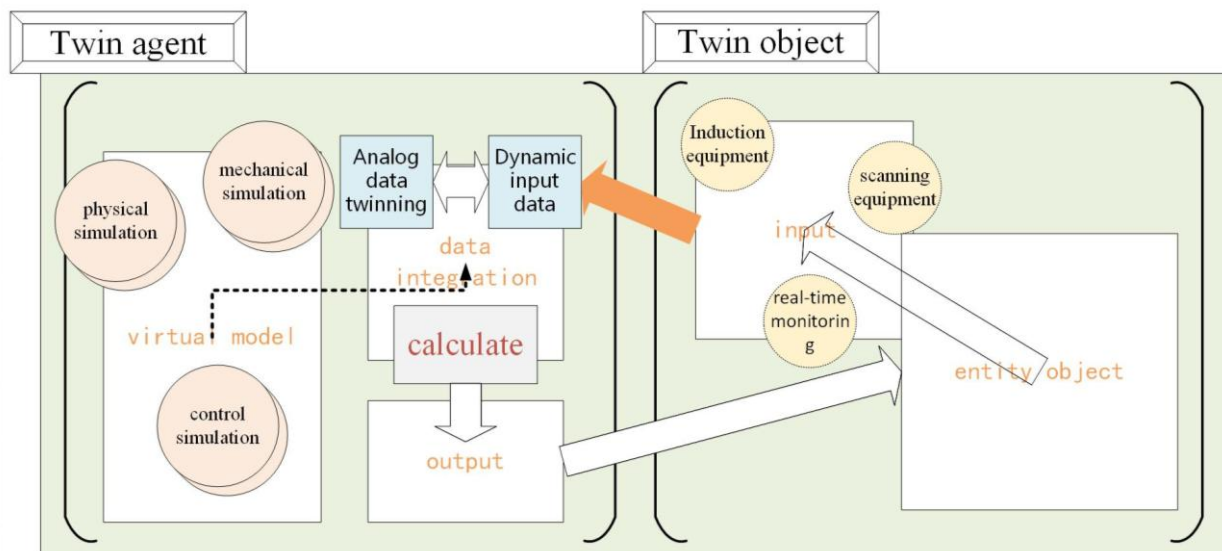


Source: This study.

Figure 3: Structure Division of Digital Twins

Application Fields

In the field of application, The digital twin (hereinafter referred to as DT) is divided into the metaphysical Visual digital twin (hereinafter referred to as VDT) and the accurate and precise Industrial digital twin (Industrial digital) based on the depth of technical application and the breadth of system construction twin (hereinafter referred to as IDT). The main purpose of VDT is to visually present the project theme, which usually exists apart from the twin object, usually as a means of publicity and presentation to show the characteristics of the project field to outsiders or knowledge learning objects such as school-age children, tourists and professional beginners. The main division of IDT and VDT is based on the existence relationship between the twin subject and the twin object, that is, the existence relationship between the twin project and the project corresponding to the real world. In IDT, the subject and object exist and interact at the same time, which makes the operation status and front-end control bridge of the entire industry and project can be achieved from DT. The data reference to the interaction becomes the primary core of the IDT rather than the twin itself (Figure 4).



Source: This study.

Figure 4: General framework for industrial digital twins

Application

In terms of application, compared with VDT aimed at traditional culture and science and education media, IDT is divided into more detailed systems according to the needs of the object. The digital construction of industrial system operation system is mainly aimed at the operation and maintenance of monitoring equipment system and the construction of overall information architecture, and the design of specific engineering projects focuses on intelligent design through DT means.

Twin Object

In terms of twin objects, VDT objects are mostly existing classic cases, which are specifically the existing historical preservation, the reconstruction and reproduction of traditional cultural bodies, the interpretation of characters and events, and the display of existing achievements in the field of science and technology industry. IDT objects are mostly real image models, focusing on full-feature simulation, and information simulation of all elements affecting the twin, such as the input information of sensor detection equipment, increases the reliability of dynamic twins, and helps to improve the accuracy of DT.

Twin Data Type

VDT data. In static digital twins, the corresponding data of the scene with fixed content is easier to obtain than that of the dynamic digital twin, and its content will not change over time. The digital twin designer needs to build a model or picture of the entity object to be presented. In the same field as VDT, the twin of dynamic digital twins is different from the twin object, the scene content becomes rich, and the presentation content of the twin object is more in the form of animation, showing the physical structure and operating mechanism principle of the twin object. The dynamic twinning in IDT requires that on the basis of the existing idealized running algorithm of the object, the input dynamic monitoring information of the object can be captured and imported with high precision. In terms of the construction of algorithms, the theoretical summary of the operation algorithms of the laboratory and the initial/ideal state of the object and the competitive algorithm of the project team during the operation and maintenance are respectively summarized. The theoretical algorithm helps us quickly build an idealized model, while the addition of the empirical algorithm can carry out the realistic operation of the twin model to a greater extent. To achieve an "off spec" virtual twin.

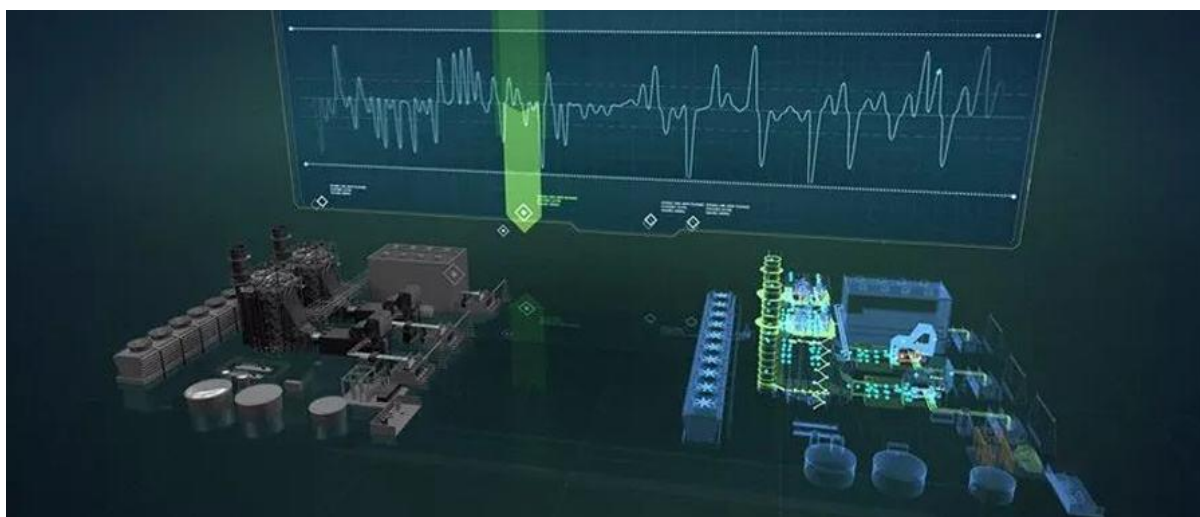
Visual Interactive Terminal

On the DT terminal, the static digital twin mostly adopts projection-type method and displays to the viewer with plane vision equipment as the carrier. The application methods include augmented reality technology (AR), virtual reality technology (VR), ultra-wideband technology (UWB), indoor navigation technology (iBeacon), holographic projection technology (FIG. 4), somatosensory technology and multi-touch technology. Among them, AR, VR, iBeacon, and motion-sensing technologies all involve sensory interaction and visual film and television design, but without exception, the static digital twin is "constant", and its content including interactive feedback is determined before being put into use and does not change due to the viewer, and the dynamic digital twin in VDT is also the twin itself is always moving. IDT presents the dynamic digital twin of the twin object in the form of an interactive platform (dynamic management platform). As a collection of relevant information, it integrates the input and output information of the object into floating data and presents it in front of the user. It can also send command signals to input the twin object (including the twin object entity) in the cloud, as shown in Figure 6.



Source: www.d-arts.cn(2021)

Figure 5: The Forbidden City end gate digital museum holographic projection

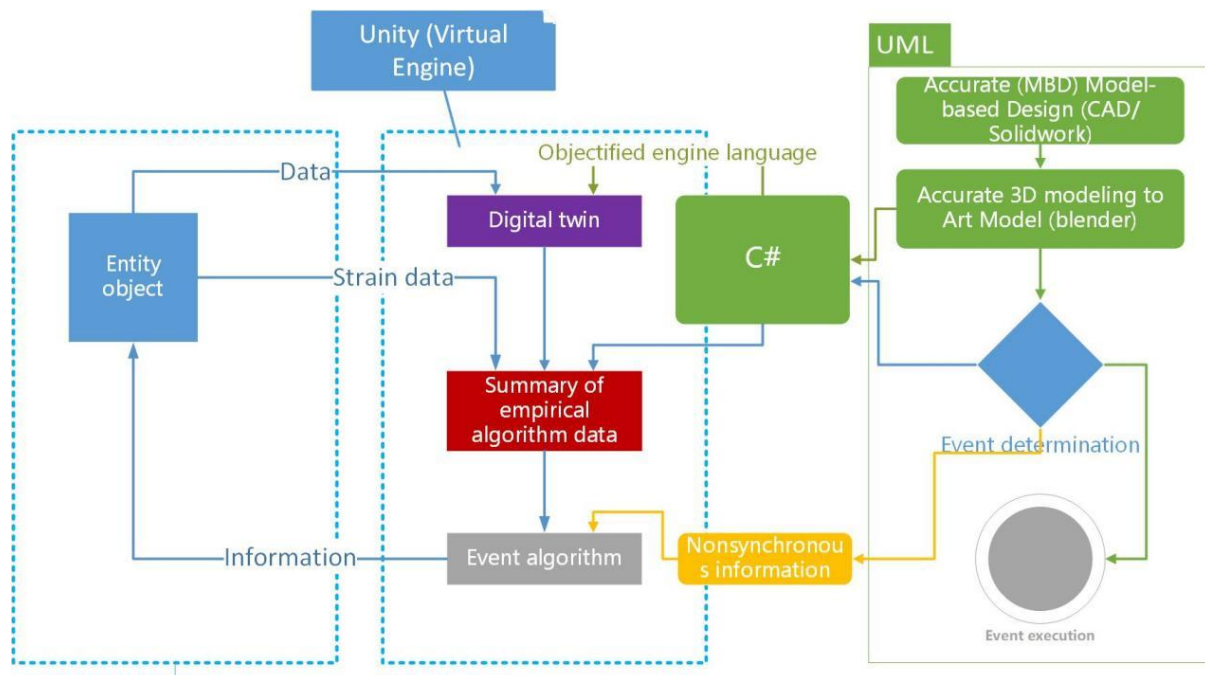


Source: www.ztmapinfo.com(2020)

Figure 6: Digital twin factory

Application Method of Digital Twin Front-End Design

This paper summarizes the following implementation procedures and the computer language used in the digital twin vision model. Summarize front-end behavior based on UML: (MBD) Accurate modeling based on modeling → Art triangle model (for unity engine and reduce engine operating pressure) → Twin project team provides data and corresponding algorithms → Algorithm and triangle 3D model import into unity virtual engine → Load behavior model into 3D model using C# language → project team nested algorithm into virtual engine → Input Exit terminal (not covered in this article) (Figure 7)



Source: This study.

Figure 7: Digital twin front-end

Enterprise Management and Operation of Digital Twin Technology in Service Level

In order to improve the data reliability and resource coordination provided by digital twin technology in the management and operation of enterprises at the service level, The successful application of the DIKW chain theory proposed by Ugisgulen et al.(2024), -- the spiral law of Data → Information → Knowledge → Wisdom in lean production indicates that under the dynamic mechanism of enterprise information resource coordination under the digital twin technology, The possibility of intelligent digital transformation of "three engines and four drives".

Digital Twin Technology in Industrial Production System Error Solution

The solution to the offline phenomenon of digital twin technology in industrial production system. Focusing on the problems such as poor intuitiveness of data, low sharing of key information, and unclear location of sections, Anqing Zhu et al.(2024) built a twin model of production line of ship section construction in equal proportions, considering the flow direction of section process and storage yard resources. The twin data-driven management system and data storage management method are constructed to provide the data foundation for the monitoring of the segmented construction. Application The virtual engine unity and 3D modeling 3D/Max software are used to provide a visual platform for dynamic data query and decision basis, and provide support for the integrated application of various information in the construction and management of ship products.

ARESEARCH ON THE APPLICATION METHOD OF DIGITAL TWIN MODEL CONSTRUCTION

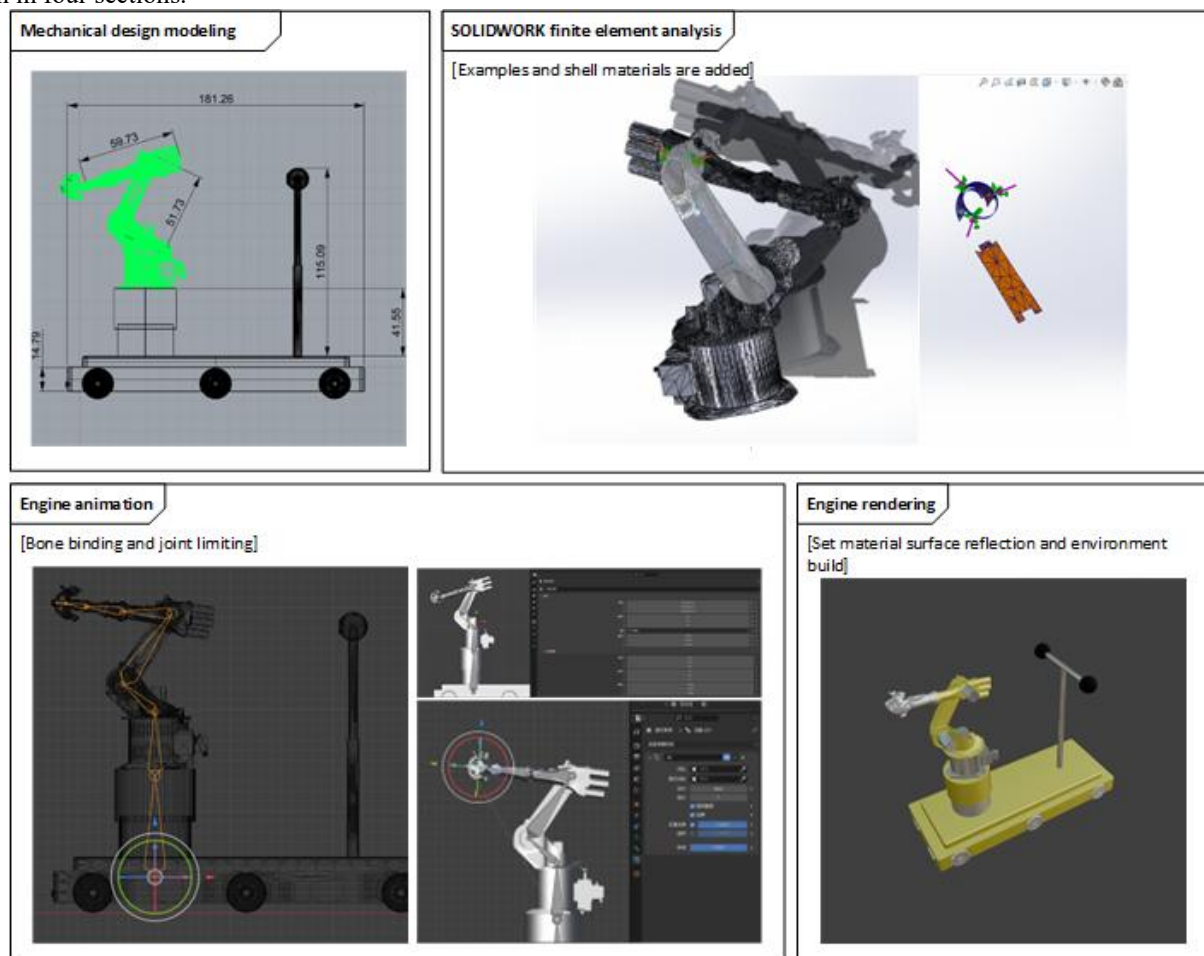
Digital Twin Application Method Outline

At the front end of production and manufacturing, between the feasibility analysis of industrial projects and the prediction of different risks that may occur in the implementation and promotion of the project, the simulation analysis of the project object and the visual presentation of the principle display are the main tasks of product designers and animation designers. Choosing blender's Modeling and rendering engine helps designers bring to life the highly technical and logical rigor behind art, video, and industrial projects through modeling, animation, effects, rendering, and information interaction. We focus on the Geometry Node Editor in blender Engine, which has plenty of physical geometry application methods for us to choose from. Compared to the unity engine, the instructions in blender are more objective-oriented, allowing non-computer designers to better understand the design object and design in a result-oriented way.

At the same time, due to the diversity of the field of the mirror object and the required professional application environment, the transformation between multi-platform, multi-software and multi-format has become the main technical difficulty between industrial simulation and industrial digital twin. For example, ANSYSWorkbench workflow, Solidwork workflow and film design workflow of Unreal engine Unity and UnrealEngine have a common behavior pattern, but there is a big gap between the model language and its own working mode. Understandably, industrial simulation pays more attention to the physical existence of specific mesh in the model and device object object, that is, the physical properties of materials science in areas such as force field, magnetic field and heat conduction, while for the Unreal Engine with programming as the framework, the logical relationship of the behavior of the object under each Class. It can be simply understood that the industrial simulation modeling is the hardware simulation of the digital twin project, and the Unreal Engine intervention is the simulation of the software port.

Digital Twin Modeling Workflow

As an example, this paper introduces a new idea of digital twin visual modeling, which mainly relies on the workflow combined with Solidwork and blender to analyze and conclude the single digital twin demonstration behavior of a robot arm in four sections.



Source: This study.

Figure 8: Digital twin visual modeling

SolidWorks Mechanical Design Modeling

SolidWorks is one of the most widely used mechanical design software that provides designers with a powerful platform to create complex three-dimensional models. In the context of digital twin vision modeling, SolidWorks' role is to build an accurate physical entity model that will serve as the basis for subsequent analysis. In SolidWorks, designers can draw two-dimensional blueprints of their models through a series of sketching tools. These sketches can be converted into 3D features such as stretching, rotating, scanning, and lofting to build a complete 3D model. Designers can also take advantage of SolidWorks' parametric design capabilities to control the size and shape of the model by setting variables and constraints, making the model more flexible and adjustable. The editing process of the model involves refining and optimizing the model that has already been created. This may include removing unnecessary features, adjusting dimensions, fixing geometric errors in the model, or adding detailed features such as threads, keyways, etc. SolidWorks provides intelligent selection and editing tools, such as Feature Manager and Design Assistant, that improve the efficiency and accuracy of editing. An important step is to verify the accuracy and reliability of the model. SolidWorks has built-in validation tools such as interference checks, dimensional conformance checks, and surface quality analysis. These tools can help designers identify potential problems in the model, such as interference between parts or geometric defects in the model, thereby ensuring the functionality of the model.

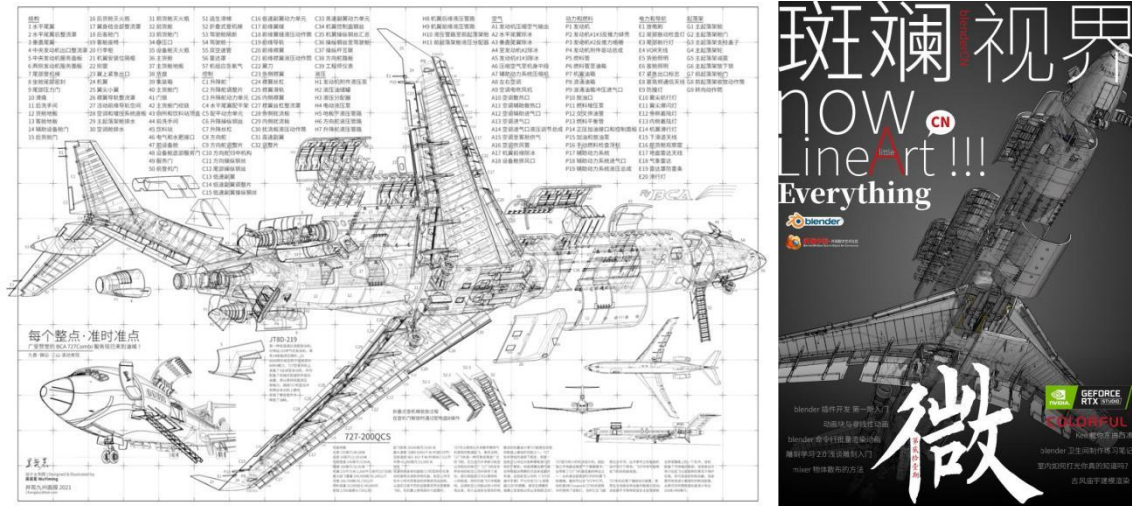
SolidWorks Finite Element Analysis

Finite element analysis (FEA) is a method to evaluate the performance of mechanical structures under stress. In digital twin vision modeling, SolidWorks finite element analysis tools can be used to simulate and predict the behavior of the model. Before finite element analysis, the model needs to be divided into many small grid units. Each grid cell represents a tiny part of the model, and in this way, complex models can be reduced to mathematical models that can be numerically calculated. The quality of the grid directly affects the accuracy of the analysis, therefore, the designer needs to ensure that the grid division is reasonable and uniform. In order to perform an accurate finite element analysis, the designer needs to

apply the appropriate loads and constraints on the model. Loads can be force, pressure, or temperature, etc., while constraints simulate fixed and boundary conditions in real-world applications. Correctly setting loads and constraints is critical to simulating and predicting the behavior of the model. After completing the finite element analysis, the designer can obtain various data and diagrams about the performance of the model, such as stress distribution, deformation and vibration characteristics. These results are crucial for understanding the strength, stiffness and stability of the model and can provide important reference information for mechanical design and optimization.

Reasons to Choose Blender

Blender's full process toolset allows users to customize the workflow according to the specific needs of their project, and can optionally turn certain features on or off, which greatly improves the computational efficiency of the computer, especially in large scenarios. Meanwhile, blender has achieved remarkable success in the field of computer graphics, as early as 2021, Yiming Wu published his Blender Industrial modeling in the blender Chinese Forum, which makes us imagine the possibility that one day industrial designers will use a virtual engine to directly and quickly model the possible and random events of the entire life cycle of their products and all scenarios.



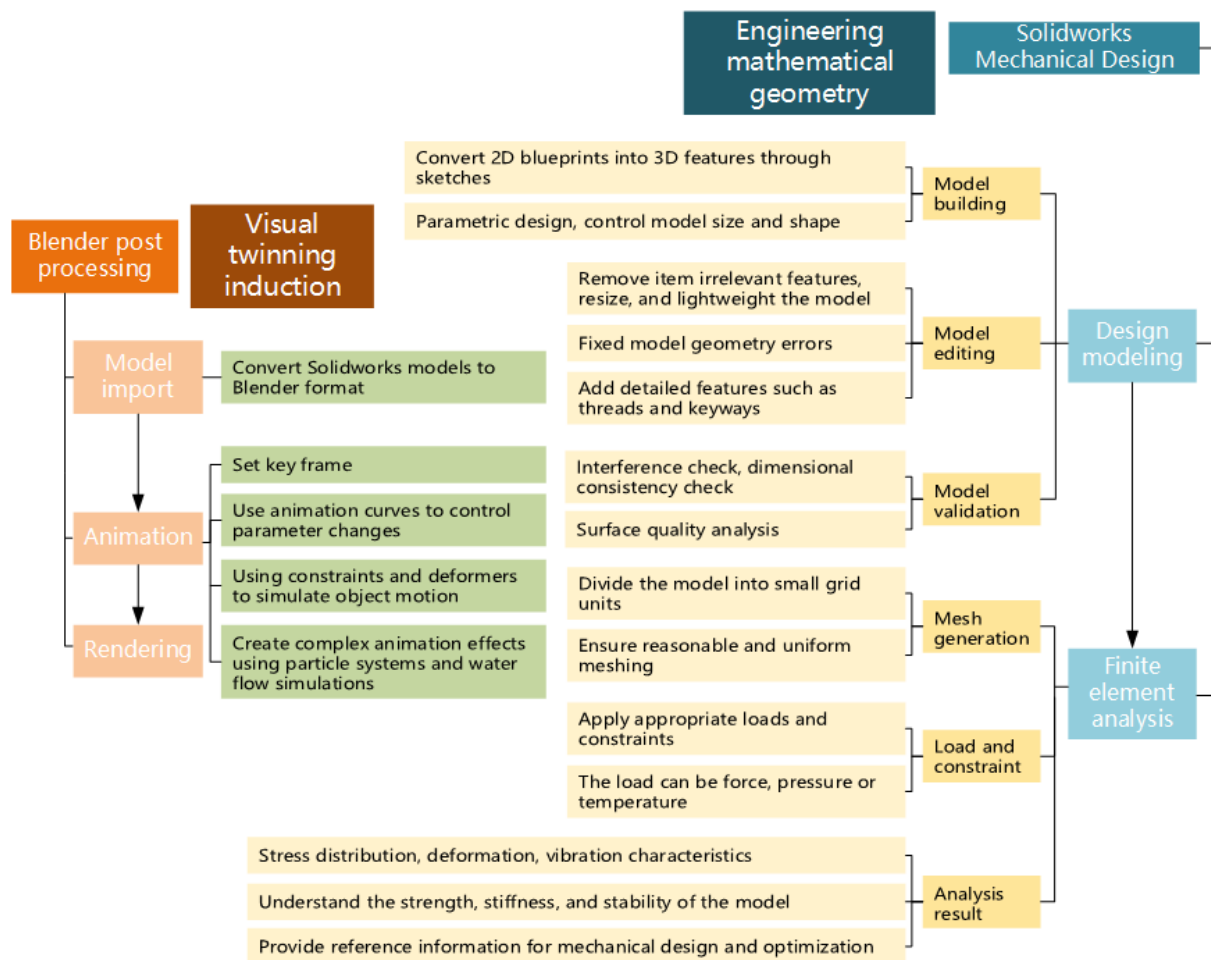
Source: BlenderCN Open Source Design Art Community.
Figure 9: DIY creations by Chinese designer Wu Yiming.

Blender Engine Animation

Blender is a powerful open source 3D modeling and animation software that transforms models created by SolidWorks into animations for more intuitive presentation and analysis. The process of importing a SolidWorks model into Blender involves converting the model file into a format that Blender can recognize. Once the model is imported, the designer can further edit and animate it in Blender. In Blender, designers can use a variety of tools and features to create animations. This may include setting keyframes, using animated curves to control parameter changes, and using constraints and shapers to simulate the movement of objects. Blender also offers simulation features such as particle systems and water flow simulation that can be used to create more complex animation effects. Once the animation is finished, it needs to be rendered in order to convert the animation into a video file that can be watched. Blender offers several rendering engines, including the built-in Cycles renderer and the Eevee real-time renderer. Designers can choose the right rendering engine according to their needs, and weigh the quality and speed of rendering.

Blender Engine Rendering

Rendering is the final step in the animation production process, which converts a 3D scene into a sequence of 2D images, resulting in a video that can be watched. Blender offers a variety of render Settings and options that allow designers to adjust the quality of the render according to the needs and budget of the project. In Blender, render Settings include resolution, frame rate, render layer, and render format. Designers need to set these parameters according to the final output requirements to ensure that the rendered animation has the desired clarity and smoothness. The rendering process can be very time consuming, especially for complex scenes and high-quality output. Blender offers a variety of optimization tools and tricks, such as ray tracing, instantiation, and occlusion elimination, to help reduce rendering time while maintaining rendering quality.



Source: This study.

Figure 20: Digital twin Workflow

IN THE VISUAL SIDE OF THE OPERATION METHOD AND INSPIRATION FOR PRODUCT DESIGN

From the perspective of product design, the visual port design of digital twin mainly experiences from the three-dimensional modeling of project objects to the design of interactive interfaces, from the induction of data to the application of digital twin animation kinematics algorithm programming.

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