

# Towards an Open-Source Industry CAD: A Review of System Development Methods

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**Abstract:** Due to the industry knowledge barrier, general computer aided design (CAD) software cannot do everything in digital manufacturing by itself, and industry CAD, therefore, occupies a crucial position in the CAD industry. To develop industry CAD smoothly, open-source is the best choice. We analyzed recent examples of industry CAD development and divided the development methods into four types: development based on the graphics development environment, development based on geometric modelling kernel, secondary development based on general CAD, and hybrid development. We analyzed the characteristics of various methods and believe that the method based on the hybrid development of the geometric modelling kernel and the graphics development environment is the best open-source industry CAD development method. We proposed a system architecture of open-source industry CAD for reference and conducted a preliminary exploration of the reference architecture to verify its feasibility.

**Keywords:** CAD development method, industry CAD, open-source, system architecture

## 1 INTRODUCTION

Digital manufacturing is developing rapidly, and CAD software has become one of the main forces in this industry. However, the current general CAD software cannot fully meet the requirements of various industries for CAD software functions, especially when it comes to industry standards and specifications. Industry CAD has become an indispensable part of CAD industry, and the development method of industry CAD has gradually attracted the attention of developers. To develop industry CAD smoothly, open-source is the best choice. Open-source will allow developers in different industries to refer to the CAD development methods of other industries to develop CAD for the industry they need. At the same time, the extension of excellent open-source architecture can also accelerate the development of industry CAD systems, improve development efficiency, forming a virtuous circle of industry CAD software development.

This paper investigates how to develop open-source industry CAD systems. We divide current industry CAD development methods into the following four types: development based on the graphics development environment, development based on geometric modelling kernel, secondary development based on general CAD software, and hybrid development. We analysed the characteristics of different methods according to industry CAD development examples. We analysed their advantages and disadvantages associated with open-source, development difficulty, development cycle, development results, efficiency, performance, etc., and conducted a unified comparison and evaluation.

Based on the survey, we put forward a development architecture with good applicability for open-source industry CAD systems and conducted a preliminary exploration for the feasibility of the reference architecture. Through comparative testing, the feasibility of the architecture was initially verified.

The organization structure of this paper is as follows: Section 2 briefly introduces typical general CAD software and its composition, function and application scope. Section 3 introduces four methods of industry CAD development and analyzes their characteristics combined with examples. Section 4 presents our recommended development architecture for open-source industry CAD

system, and analyzes it through practice. Section 5 summarizes our work and looks forward to the next step.

## 2 GENERAL CAD SOFTWARE

Since the first CAD system Sketch Pad [1] came out in 1963, the general CAD software has undergone a transition from 2D to 3D, and its functions have gradually expanded to implement graphics drawing functions, powerful graphics editing functions, multi-mode secondary development functions, professional user customization functions, multiple graphics format conversion functions, and flexible data exchange functions. Current CAD software has covered engineering drawing, industrial drawing, clothing processing, electronics industry, civil engineering, garden engineering, and other industries.

At present, common general CAD software includes UG, FRO/E, AutoCAD, CATIA, SolidWorks, FreeCAD, etc. These CAD software are composed of the geometric modelling engine, visualization engine, geometric constraint solver, UI framework, etc., provide stable and accurate 2D drawings, flexible and complex 3D parts transfer, large-scale file format conversion, and multi-mode secondary development, etc. However, general CAD software cannot meet the requirements of various industries, the peculiarity of industrial parts, and industry assembly rules in terms of functions. In terms of performance, it may not meet certain industry's special requirements for the functional performance of a certain module. For example, the clothing industry [2] that draws clothes sketches in the 2D environment often needs to evaluate their effects in the 3D environment, and general CAD software does not provide the transformation function that requires clothing expertise; the criminal investigation industry [3] uses mobile devices to collect On-site evidence, which requires CAD software to provide the conversion interface of special instrument data, the compatibility of different hardware data, and the standardized rendering of graphics data. Therefore, the current general CAD software still needs improvement.

Nowadays, the requirements for CAD performance in various industries are complicated. General CAD cannot meet the professional needs of all industries, which requires CAD developers to develop industry-specific

CAD systems for each one. The development method of industry CAD is the focus of this paper.

### 3 INDUSTRY CAD DEVELOPMENT METHODS

In this section, based on the development environment of the core functions of the CAD systems, we divide the industry CAD development methods into development based on the graphics development environment, development based on geometric modelling kernel, secondary development based on general CAD software and hybrid development. We will introduce their dependent environment, examples, and characteristics.

#### 3.1 Development Based on Graphical Development Environment

The essence of the graphics development environment is an application programming interface (API) library, which provides users calling APIs with operations such as drawing, deformation, and displacement of basic geometric figures. It does not provide operations with CAD characteristics, such as stretching, rotating, sweeping, and Boolean operations.

Currently, the popular graphics development environment is OpenGL (Open Graphics Library) and DirectX and their extended versions, both of which have good graphics expression and rendering capabilities. In the process of CAD development, OpenGL provides splines and complex graphics and is superior to DirectX in terms of performance and development. Therefore, OpenGL is often used for the development of CAD systems, while DirectX is often used for animation and simulation.

Yuan Yan et al. [5] developed CAD software for the design and manufacture of corrugated boxes based on OpenGL. The system builds corrugated boxes with complex geometric shapes through OpenGL, provides designers to design corrugated boxes through parameter characteristics and test their industry properties like load-bearing, etc.

Eduardo Calabuig-Barbero et al. [6] implemented a high-compatibility shoe CAD model based on OpenGL to optimize the visualization function of the shoe CAD systems. This model will be used in the shoe CAD systems to display different material designs.

Xiaowen Qi et al. [7] developed a CAD system for garden design based on OpenGL and used OpenGL to expand the garden modelling required for garden design. The system provides terrain design, planning design, planting design, sprinkler design, data statistics, construction drawings, rendering, and animation. Designers directly call and parametric edit 3D modelling in the system for 3D design. With the 3D views, the system enables designers to design garden scenes intuitively, and experience the design effect realistically.

F. Kober et al. [8] developed a power configuration CAD system based on OpenGL, which shows the main features of power and geometric data in geographic positioning. The system uses OpenGL to display the power lines of each area.

Jun Xu et al. [9] developed clothing design CAD software based on OpenGL and it is used to design skirt models and provides a parametric modification of skirt

length and contour folds. The system constructs the geometric shape of the skirt through OpenGL. When designers and customers customize skirts, customer needs will be intuitively reflected by adjusting parameters.

Gao Qiang [10] developed a CAD system for designing glass packaging containers based on OpenGL. The system uses OpenGL to generate a 3D model of the glass container, and designers modify the glass container by adjusting its parameters.

Yin Shuyun [11] developed a CAD system for fiber winding design based on OpenGL and simulates the process of winding fiber on the winding core mold. OpenGL draws the winding core mold and the winding fiber, and the designer designs by adjusting the parameters of material and winding trajectory.

We found that developing CAD systems based on graphics development environments generate complex geometric shapes directly, and provide designers to design through parameterized adjustments or call models directly. The system provides designers with an intuitive visual design platform or tests the models based on industry regulation.

The graphics development environment does not provide traditional CAD operations such as stretching, rotating, and sweeping, which is not convenient for developers to develop similar functions to provide designer operations. Therefore, most of the CAD systems developed by this method do not provide designers to generate 3D models through 2D sketch editing directly. At the same time, the graphics development environment provides functions directly editing complex geometric shapes; thus, developers can generate complex geometric models through curve modelling. By the reserved APIs, designers can flexibly edit complex parameterized models.

In terms of function, the systems developed by this method have single function and simple structures that provide designers to generate preset geometric models and perform parametric editing directly. The method will be under consideration while developing simple mobile CAD systems.

This method requires developers to have a good foundation in computer graphics and build complex geometric models by programming. It requires a great deal of work and long development cycle to implement a completed CAD system. But since the underlying function of the system is implemented by developers themselves, it provides high freedom for development. The underlying functions are fully oriented towards the development of system functions, and the system executes effectively. During development process, the usage of closed-source is avoidable, so the method can effectively reduce development costs and facilitate open-source research. Using this method to develop industrial CAD, the development of industry-specific functions will only be limited by the technical level of developers, and the development of industrial functions related to traditional CAD operations is more difficult than in other methods.

In terms of technical routes, the development of industry CAD systems based on the graphics development environments requires priority to solve programming problems of geometric models, set parameters according to industry needs, write verification algorithms for the character of the model, and encapsulate the system's

interface by UI framework. The graphical development environment often acts as a visualization tool in the system.

### 3.2 Development Based on Geometric Modelling Kernel

The geometric modelling kernel is a class library essentially, and it provides the basic operations of the traditional CAD system, including 2D sketch operations and 3D model operations, etc.

The current mainstream geometric modelling kernels include Parasolid, ACIS, OpenCASCADE, etc. As the world's first geometric modelling kernel, Parasolid has powerful, complex, and stable geometric modelling functions, and is now the most widely used geometric modelling kernel; ACIS and Parasolid are from the similar scientific research team, with advanced architecture, perfect API System, and high-efficiency general entity modelling technology; OpenCASCADE, as the only open-source geometric modelling kernel currently, has good curve processing capabilities.

Mykhaskiv [12] designed a CAD system architecture based on OCC that combines the computational grid using flow simulations (DFC). The system based on the architecture provides efficiently designing of geometric models such as fluid curves.

M. Coleman et al. [13] developed a CAD system based on OCC to quickly generate 3D models of nuclear reactors. The system provides neutronics data analysis, which is convenient for the nuclear power industry to confirm the safety of design work.

Zhong Jiao [14] developed a CAD system for designing paper-cut styles based on ACIS. The system takes the structure of the ACIS geometric modeling kernel as the core of the architecture to implement the entire system.

Qingxi Xie [15] developed a CAD system for base station site selection based on ACIS. The system uses the ACIS kernel as the core of the system display architecture. By adding two automatic algorithms for base station site selection, the data from Google Maps is analyzed and processed to implement automatic location selection.

Amit Kumar Bedaka et al. [16] developed a CAD system for robotic arm path simulation based on OCC. The system uses CAD offline programming technology to increase design efficiency. OCC serves as the key core technology in the system for each application module.

Thanh Hai Tuan Tran et al. [17] developed a CAD system for additive manufacturing (AM) based on OCC. The system uses feature recognition to analyze the detachability of the auxiliary bracket during the AM process. Feature recognition, as the core part of the system, is implemented on the basis of the topology of the OCC geometric model.

Martin Siggel et al. [18] introduced an open-source CAD system for aircraft simulation based on OCC. The system modeling strictly follows The Common Parametric Aircraft Configuration Schema (CPACS) industry standard and provides the design and optimization of aircraft. The system relies heavily on OCC to implement the functions of the system.

Li Yanfeng et al. [19] developed a CAD system for quantum chip design based on OCC. The system provides parametric editing of models from the standard parts

library to generate quantum parts automatically. The work focuses on the meaning of independent copyrights around OCC.

Wang Tong [20] developed a CAD/CAE system for the riser burning process of steel castings based on OCC, using Drosophila optimization algorithm, hybrid numerical simulation, and other intelligent analysis algorithms to optimize the parameter settings of steel castings and improve the steel casting quality. The CAD part of the system is implemented on the basis of OCC.

We found that when developing an industry CAD system based on a geometric modeling kernel, the geometric modeling kernel is taken as system core, and most of the basic CAD functions are implemented into the basis of the geometric modeling kernel function. System developers put much energy on design data processing, design parameter setting, design method simplification, etc. The system allows users to design industry parts referring to industry specifications.

This method is convenient to implement the basic functions of the CAD system, such as Boolean operations, stretching, sweeping, and other geometric model operations, and is currently the most common method for general CAD software development such as CATIA, SolidWorks, AutoCAD, T-FLEX [21].

The geometric modelling kernel packs basic geometric models such as points, lines, and surfaces to unify complex geometric operations. It makes the freedom to implement complex geometric models slightly worse than the development method based on the graphical development environment. At present, only OCC is open-source as the common geometric modeling kernel. Therefore, it is necessary to consider the lack of open-source materials when conducting open-source research and maintaining independent copyrights.

Through this method, most of the basic functions will be implemented by expanding the function of the geometric modelling kernel. Then, add geometric constraint solvers and other core components of CAD software, design industry standards and methods, and implement interface packaging to achieve a complete industry CAD system. The development effect of interface display functions, such as high-precision rendering and special deformation, which are specially required by the industry, will be limited by the interface rendering interface provided by the geometric modeling kernel. However, the open source geometric modeling kernel is often difficult to fully meet the needs of industrial CAD rendering.

### 3.3 Secondary Development Based on General CAD Software

The secondary development based on general CAD software is to make custom modifications or function expansions on the basis of CAD software to implement the design of the developer's estimated function. In principle, this method does not modify the basic function of the original CAD software, but only calls the secondary development APIs provided by the CAD software.

Most general CAD software will provide APIs that supports secondary development, such as Grade and User Function of UG, Pro/TOOLKIT and Automation

GATEWAY of Pro/E, Automation and KnowledgeWare of CATIA, SolidWorks API of SolidWork, AutoLISP and Visual LISP of AutoCAD, workbench of FreeCAD, etc. At present, expanding CAD functions based on the secondary development of general CAD is the most common method to develop industry CAD systems.

Gongli Tan [22] developed a CAD system based on CATIA to generate feature libraries of various angles and liquid levels automatically. The system obtains the characteristic data of the oil silo from various angles, calls CATIA's volume calculation function to generate oil volume data under different angle parameters, and automatically stores the data in the database. The system is a functional expansion of CATIA.

Lulu Hou [23] developed a CAD system that provides the standardized drawing of traffic signs based on the AutoCAD software secondary development interface Svisual LISP and ActiveX.

Bingqian Zhao et al. [24] have implemented a CAD system that provides the automatic drawing of ground cross-sections and cross-sections designing based on the secondary development of AutoCAD's VBA language.

Wenwu Mao et al [25] developed a CAD system based on the VBA language in AutoCAD to parametrically generate the drawings of jet aerators. Following user requirements, the system reads the models in the database, assigns values, and generates drawings automatically. The system relies on AutoCAD as a module in AutoCAD software.

Yan Wu [26] implemented a CAD system for plane pattern design based on the secondary development of AutoCAD. The system was implemented through the secondary development APIs of VBA. It provides standardized ethnic pattern generation and parametric editing, and editing of tool layout conversion. The system expands the design material library on the basis of AutoCAD functions, provides standardized layout schemes and implements the CAD functions required by the industry. The system is an extension module of AutoCAD.

Ying Wei [27] developed a wiring CAD system for the construction industry based on AutoCAD. The system mainly provides the wiring scheme of engineering standards and divides the functional blocks of the CAD system according to national standards.

D. Nasulea [28] based on CATIA, developed a CAD system for the parameterized generation of rotating sheet metal composite mold that provides cold press forming. The system focuses on quick response to user modification. The function of the system depends on the operation of model generation and editing in CATIA.

Gang-Yeon Kim [29] developed a CAD system for hot stamping technology molds based on CATIA. The system allows users to generate 3D mold models by providing data such as surface models of parts and the number of cooling water channels automatically and optimize the generation of mold model and 2D drawings. The system is implemented based on two secondary development APIs provided by CATIA, KnowledgeWare, and CAA (CATIA SDK).

E. Jayakiran Reddy et al. [30] designed a CAD system based on industry knowledge to generate industry models quickly. The system is implemented based on the VBA

secondary development APIs provided by SolidWorks and calls its functions to generate a macro program based on industry knowledge and automatically generates CAD models through the macro program.

Xinzhong Chang [31] implemented a CAD/CAE system for generating bridge cranes based on SolidWorks. The system generates 3D models of bridge cranes according to input parameters and supports related stress analysis.

Based on CATIA, IsadSaric et al. [32] have implemented a CAD system that supports the generation and analysis of parametric intelligent pressure vessels. The system allows users to input key parameters to generate CAD models automatically.

We found that CAD systems based on secondary development methods are guided by functional architecture and apply general CAD software functions. There is no need to consider the underlying design and implementation during the development process. The interface design work is simple, and there is usually no need to develop the traditional functions of CAD software.

At the same time, the development relies heavily on CAD software, and the implementation function will be an extension module of CAD software. Most CAD software does not provide the underlying data port and intermediate processing data port, it is difficult to get the software intermediate data or get part of the complex data accurately. It is impossible to get and modify the underlying data of software. The developed CAD system needs to have good compatibility to deal with abnormal problem caused by the update of general CAD software.

Most general CAD software provides secondary development APIs, but the software may not be open-source, so the method is not friendly to open-source research work. Of course, using open-source CAD software can alleviate this problem.

It is necessary to study the secondary development APIs provided by general CAD software to apply this method. Then, design the functional architecture according to the functional requirements, implement the functions and carry out the necessary interface encapsulation to complete required CAD system. The development of special functions required by industry CAD will be limited by the interface provided by CAD system. It is difficult to obtain intermediate data required by some special functions and easy to produce redundant data processing.

### 3.4 Hybrid Development

Recently, some scholars have studied the data interoperability between CAD software [33], the comparison of data conversion performance between CAD software [34] and the process-based cross-CAD data exchange [35] and other issues. These studies have provided theoretical support for the data transfer between CAD software, and have made it possible to apply the above methods for CAD system development hybrid.

HuaDu et al. [36] developed a CAD system based on OCC and FreeCAD that converts the CAD model into a file that can be read by the nuclear fusion simulation software cosROM. The system uses OCC as the system function-core and FreeCAD as GUI. The data format specified by



the industry software generates files provided by the cosROM software.

Xiaohua Qi et al. [37] developed a CAD/CAM system for the design and construction of offshore jacket platforms based on AutoCAD and OpenGL. The system uses the PTMAK system based on AutoCAD secondary development to generate jacket engineering drawings automatically and develops a Visual cutting simulation function using OpenGL.

Yang Haoya [38] developed a CAD system based on CATIA and OpenGL for parametrically generating 3D models of railway vehicle axles. The system is based on the CAA secondary development APIs provided by CATIA to develop a geometric model library of variable structures and uses OpenGL to generate the safety factor cloud map of the model.

Lu Yu et al. [39] developed a CAD system for rapid hull modelling based on AutoCAD and CATIA. The system uses the VB language provided by AutoCAD to implement the preprocessing conversion of the hull data from 2D to 3D and uses CATIA to implement the preprocessing data into a 3D model. The system integrates AutoCAD's excellent 2D data processing capabilities and CATIA's outstanding 3D modelling capabilities.

In addition, the well-known open-source CAD software FreeCAD is also implemented in this way. The system uses OCC as the geometric modelling kernel and Coin3D for geometric modelling rendering.

Hybrid methods can complement the advantages of different methods: using the graphics development environment to process image model data efficiently makes up for the problem of non-open underlying data of general CAD software, using the complete interface of general CAD software reduce the difficulty of developing a geometric modelling kernel, and using general CAD software with different characteristics optimize the design process and results, etc.

However, the hybrid method involves multiple development environments, developers have to consider the consistency and coordination of data information and the integrity and compatibility of the system. A large number of data conversions cannot be avoided. The selection of the development environment version during the development process is of great concern.

In terms of open-source, the methods hybrid with general CAD software are susceptible to the influence of general CAD software. It is hard to guarantee their independent copyrights and open-source. However, it is an appropriate choice to hybrid an open-source geometric modelling kernel with other open-source resources. This method makes up for the difference in performance between open-source resources and commercial closed source resources.

### 3.5 Comparison and Summary of Method Characteristics

By comparison, the system based on the graphics development environment is difficult to implement traditional CAD functions or to meet the functional requirements of various industries. At the same time, the long development cycle is also difficult to meet the requirements of high-speed update of industry products. The secondary development based on general CAD software is convenient for users to adapt to new functions, but the expanded functions are affected by the secondary development APIs, and it is difficult to guarantee independent copyrights. The method is not friendly to open-source. When the hybrid method involves the secondary development of general CAD, it is difficult to avoid the influence of general CAD on independent copyrights and open-source. Even if the open-source general CAD software is used for secondary development, its functional performance constraints make the development of industry CAD full of difficulties.

**Table 1** Comparison of four development methods

Method	Features	Advantages	Disadvantages	Open source
Development Based on graphical development environment	This method implements the visualization of the design process through a graphic development environment, and the system; rarely allows users to implement the model creation through common CAD methods such as drawing sketches.	The development freedom is high, the independent copyright is controllable, and it is easy to implement complex geometric models through the underlying design.	The development system requires a certain foundation of computer graphics and mathematics, which is difficult to develop and implement traditional CAD functions.	Easy to open source
Development based on geometric modeling kernel	This method implements the common functions of CAD through the functions provided by the geometric modeling kernel, and cooperates with other modules to implement the CAD system.	General development freedom, independent copyright is affected by the geometric modeling kernel, and provides the modification of some underlying functions	The development performance is affected by the geometric modeling kernel, which makes it difficult to modify.	Affected by geometric modeling kernel
Secondary development based on general CAD software	Using the secondary development APIs provided by general CAD develop function, the system development is oriented to specific functions.	The development is simple, no need to consider the underlying settings, and the underlying problems are rarely encountered	The development freedom is low, and the development function is restricted by the secondary development APIs, and it is difficult to affect the underlying layer.	Affected by general CAD software
Hybrid development	The above three methods are hybrid for development, and various methods can learn from each other's strengths.	have the advantages of the above three methods at the same time and make up for the corresponding shortcomings.	The integrity of the system is poor, the consistency of data is difficult to maintain, and a large number of data conversion issues may need to be dealt with.	Affected by hybrid development environment

Independent copyrights and open-source will also be affected by the geometric modelling kernel while developing CAD system based on it. But choosing an open-

source geometric modelling core can alleviate it. Through the work of Salvatore Auriemma et al. [40], the powerful performance of the open-source geometric modelling

kernel is shown. This method is far superior to the method based on the graphics development environment in terms of development speed and development efficiency. At the same time, we have to admit that the open-source geometric modelling kernel has a gap with commercial geometric modelling cores in terms of rendering and underlying geometric modelling, but the problem can be alleviated by mixing with the graphics development environment.

In the end, we believe that open-source geometric modelling kernel and the graphics environment hybrid development is the best way to develop an open-source industry CAD system. Most of the current open source CAD, such as FreeCAD, AnyCAD, is developed by this method. FreeCAD is developed based on the Open CASCADE, an open-source geometric modelling kernel, and Coin3D, a graphics development environment. FreeCAD independently developed the underlying data management module, document management module, basic class module and other basic modules. In FreeCAD, the Part module supports basic CAD functions. The Part module encapsulates Open CASCADE as the data base of the basic CAD function module. On this basis, it encapsulates the basic CAD functions and further supports other functional modules of FreeCAD. FreeCAD encapsulates Coin3 in the GUI module, which is mainly responsible for the framework construction and display module, and uses the model data provided by the geometric modelling kernel to render the 3D model, and then completes the model rendering of the entire CAD system.

When using the recommended method to develop industrial CAD, the open source geometric modelling kernel is the basis of the CAD system. Most of the general functions of the system are completed by encapsulating the functions provided by the geometric modelling kernel, such as the creation of basic geometric modelling, Boolean operation, sweeping, stretching, and so on. The geometric modelling kernel provides the basis for the system data model. Some modules can be designed according to the requirements of the industry, such as data storage module,

data switch module, etc., embedding industry rules and requirements in the data layer. The interface display of the system can adopt the interface rendering provided by the geometric modelling kernel, but the rendering function provided by the open source geometric modelling kernel is often not enough to meet the requirements of the industry, such as the rendering accuracy, rendering materials, the addition of complex basic models of the industry, etc. Using the graphics development environment to develop the rendering module of the industry needs can effectively meet the needs of the industry, and facilitate the completion of the precision, material, complex model and other functions of the industry needs.

#### 4 EXPLORATION OF CAD DEVELOPMENT IN OPEN-SOURCE INDUSTRY

Based on our research, we have selected the best open-source industry CAD development method. In this section, to further verify its feasibility, we propose a system architecture for open-source industry CAD and conduct a preliminary exploration of the feasibility of the architecture.

##### 4.1 Recommended System Architecture

Through our research on CAD system architecture [41-43] in some CAD research work, and Siemens' OnShape, Huatian'sCrownCAD software, and some literature [44], we propose The CAD system architecture of open-source industry shown in Fig. 1 below.

The basic layer handles the relationship between the system and the hardware, maintains the stable operation and portability of system, and the compatibility of different hardware foundations. The management function of the basic layer provides underlay function for the application functions of the upper layer.

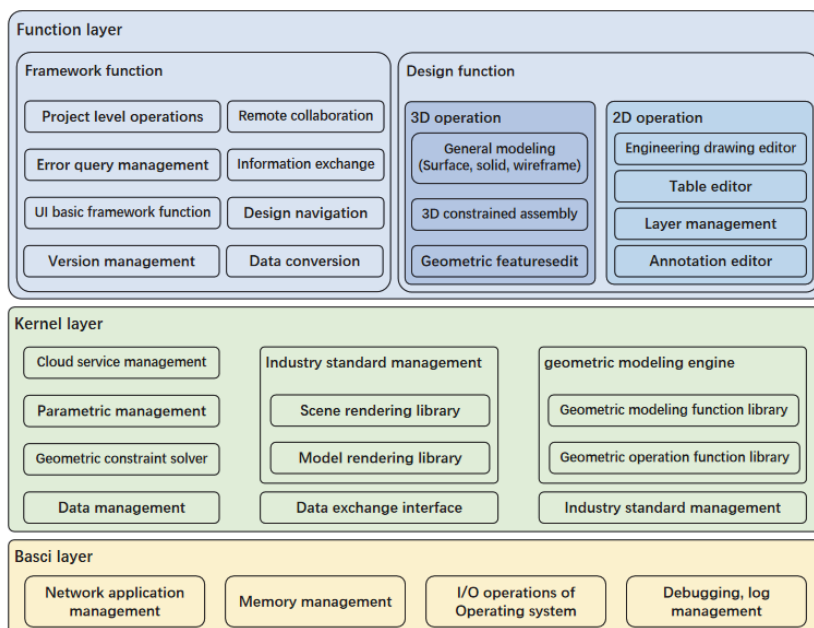


Figure 1 Reference system architecture diagram

The functions in the kernel layer will not be exposed to the designer and will be automatically called when needed. This layer mainly implements complex application function libraries to support upper-layer functional requirements. The architecture divides the geometric modelling kernel into visualization engine and geometric modelling engine, to reserve a port for hybrid development of the geometric modelling kernel and the graphics development environment from the architecture level. For systems with low requirements for geometric modelling, a geometric modelling kernel can implement the above two modules. The architecture set industry data management into the kernel layer, and industry data becomes a part of the system, implementing the industry CAD system in the true sense.

The functional layer is the interaction part to designers, which requires a user-friendly interactive interface and powerful design functions. The architecture divides it into two parts: the framework function and the design function: the framework function meets the basic needs of users for the software, and it develops in a user-friendly direction; the design function, as the core function of the system, needs excellent performance, whose optimization will impact the improvement of design work efficiency and the accuracy of designing products.

The architecture is designed for the hybrid development method based on the geometric modelling kernel and the graphics development environment. The architecture provides management of industry standards and specifications and has the characteristics of industry orientation. The architecture conforms to the current development trend of cloud services in the CAD industry and collaborative design and open-resource, it meets the requirements of CAD architecture in the future. The architecture is oriented to open-source resource design, facilitating open-source research on development results.

## 4.2 Framework Feasibility Exploration

We conducted preliminary feasibility exploration based on the proposed architecture. We choose PythonOCC, the Python bindings to OCC, as the geometric modelling kernel to implement all functions of the geometric modelling module and the visualization engine module. The parameterization of the tube and the head-closure in the static equipment of the petroleum industry is established as an industry requirement. Use Pyside2 to develop interface UI framework. Use Pycharm 2019 as a development environment.

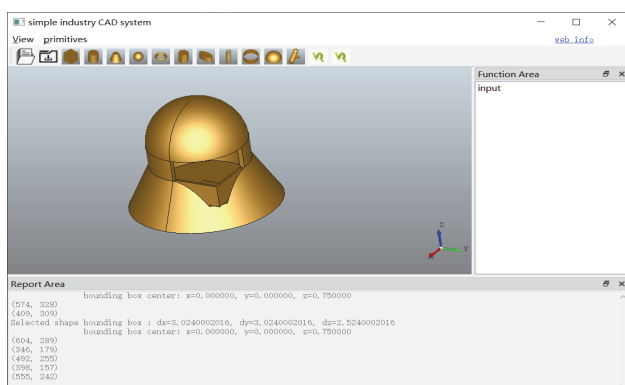


Figure 2 The simple system developed based on PythonOCC

The system expands the functions provided by the PythonOCC geometric modelling kernel to implement the basic functions of CAD software, add functions required by the industry, and perform interface packaging in the end.

We conduct a preliminary test of the feasibility of the architecture. The main purpose is to determine that industry knowledge can be transplanted to the system based on the open-source geometric modelling kernel, and to explore the method of developing a complete CAD with the open-source geometric modelling kernel.

The system initially implemented the following functions:

Parametric creation and editing of basic geometric models. The basic geometric model is the five geometric shapes of the cube, the cylinder, the sphere, the torus, and the cone that PythonOCC provides parametric creation and editing.

Import and storage of geometric models. We call the import-related and storage-related interfaces of the geometric model provided by PythonOCC to implement functions.

Parametric creation and editing of industrial parts. According to the characteristics of the industry parts tube and head closure, we build them following industry standards. The program is belonging to the kernel layer. The industry parts use the same port package as the basic geometric modelling, which allows designers to use model in same logic.

Parametric assembly of geometric models. By reading and modifying the position and features of the geometric modelling, we implement the parameterized assembly function of the geometric model.

Management and feedback of internal data in the system. We built a data structure for recording internal data of system and expanded related operations to enable data management. The development port performs automatic feedback of the internal state of the system.

Execution and cancellation of the Boolean operations. PythonOCC comes with the Boolean operation, but it has not got the cancellation of the Boolean operation. We store the geometric model of the Boolean operation through the tree structure to implement the cancellation of the Boolean operation.

System error handling. When an error occurs in the system, the system allows users to apply error handling mechanisms such as saving the current design and clearing the current internal data.

As shown in Fig. 2, the toolbar in the interface provides functions such as importing, storing, creating, assembling and Boolean operation of geometric modelling, and the Function area provides functions such as selecting and editing geometric modelling. The report area shows the feedback of internal data processing and the reminder of error handling. Web Info reserves interfaces for network data interaction. Users can design a model composed of basic geometric modelling through this system. This system has completed the function of simple CAD and can run normally, which verifies the feasibility of the proposed method.

### 4.3 Analysis of Exploration Results

The functions we have implemented cover the geometric modelling engine, visualization engine, simple industry standard management, simple data management, and simple parameter management in the kernel layer of the architecture, and the basic functions of the UI architecture, simple project-level operations, and 3D operations module in the functional layer. Thanks to the perfect function of the geometric modelling kernel, we carried out the memory management of the base layer and the operating system I/O module.

We have implemented the most basic functions of CAD system, and the function module following the architecture can be executed normally. It proved that developers could implement an open-source industry CAD system by relying on recommended architecture, which preliminarily verified the feasibility of the architecture.

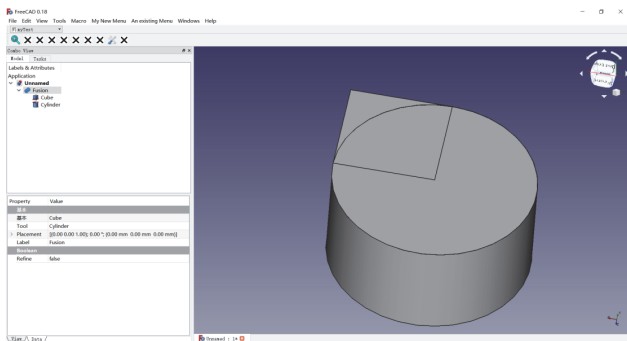


Figure 3 The simple system developed based on FreeCAD

To show the advantages of the architecture in 4.1, we executed a FreeCAD-based secondary development method to achieve similar functions to the system in section 4.2. The system is shown in Fig. 3.

In the development process, the system based on PythonOCC can implement simple functions without much tedious coding. However, the secondary development based on FreeCAD needs to program according to the rules of secondary development APIs, and the call is complicated.

During the development process based on PythonOCC, access to all data is available. The system based on FreeCAD secondary development has read-only data, such as the rotation angle of FreeCAD geometric modelling.

Based on PythonOCC development, the function of the kernel layer can be set clearly. The industry characteristics can be set to the kernel layer, so that the industry parts and basic geometric modelling can expose the same characteristics to designers. However, same functions in the system based on FreeCAD have to be packaged redundantly.

The above differences lead to the existence of many redundant data structures in the system based on the secondary development of FreeCAD, and the increasing of time complexity and space complexity of the system leads to the decrease in system performance. The system developed based on PythonOCC has no such performance degradation.

## 5 SUMMARY

Due to the industry knowledge barriers, general CAD cannot solve all industry problems, and the demand for industry CAD is increasing fast. However, the increasing demands for specific industries require the rapid and high-quality development of industry CAD. Open-source has become the way out for industry CAD development.

This paper summarizes the development methods of industry CAD system in recent years and divides industry CAD development methods into four types: development based on the graphics development environment, development based on geometric modelling kernel, secondary development based on general CAD software, and hybrid development. We summarized the characteristics, advantages, disadvantages, and difficulty of open-source for each method based on the development examples.

According to the particular needs of open-source industry CAD, we believe that the hybrid development method of the geometric modelling kernel and the graphics development environment is the best way to develop it. By analyzing the features of the method and the current development trend of the CAD industry, we carried out an architecture of the open-source industry CAD system.

To verify the rationality and feasibility of the architecture, we implemented a simple CAD system based on the architecture through PythonOCC, and compared the system with a secondary development system with the same functions, and comprehensively analyzed the performance advantages of the architecture.

For theoretical testing reasons, our implementation of the CAD system based on PythonOCC does not implement all the features of our proposed framework and does not use the graphical development environment for rendering optimization. However, the CAD system we completed has basic CAD functions, the system can run normally and the ports of other functional modules of the system are reserved, which has good expansion performance. It can preliminarily verify the feasibility of our proposed method and proposed framework. At the same time, the advantages of our proposed method are verified by comparing with the secondary development system based on FreeCAD.

The requirements of industry standards and industry features make it difficult for general CAD to perfectly fit the CAD function requirements of specific industries. The CAD system developed by open source geometric modelling kernel and graphics development environment can embed industry specifications into the underlying architecture of industry CAD software, and special industry operations can effectively avoid complex and redundant data interaction. The development of industrial CAD requires developers to master the industrial norms and characteristics of the professional industry. Through the open source method, developers and experts of industry can freely cooperate to improve the functional design and data interaction of industrial CAD, and effectively promote the development of industrial CAD. Other CAD development methods are limited by the difficulty of development, the performance of development functions, and the freedom of interaction with industry experts, which makes it difficult to achieve the same results of the proposed methods.



Our work provides a viable path for the development of industry CAD systems and provides further research directions for open-source research in the CAD industry.

We wish to solve the following problems in future work: our system is not hybrid with the graphics development environment; the recommended architecture has a fuzzy division of cloud services and industry information management; to be a completed CAD system, our system needs the support of other open-source resources like geometric constraint solvers.

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