An Annotation Management System for Collaborative Computer-aided Design

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Abstract. The interaction activities of designers using computer-aided design (CAD) software packages are usually seen as the process of capturing design knowledge. However, without annotations, it is hard to understand the context of the product design, which leads to difficulties in reusing design knowledge. Based on syntactic rules, annotation classification, and representation rules are defined. Too much annotation content for the 3D model of the entire device structure leads to confusion in the interface. Therefore, we propose a Model Knowledge Base (MKB) system to parse annotations and models and save them in a cloud database, which becomes archived knowledge sharing within teams or organizations. Finally, we verify the value and usefulness of MKB through a two-stage survey questionnaire combined with a qualitative and quantitative analysis process. The results indicate that MKB can effectively capture and save designers' implicit knowledge, thereby reducing the risk of future knowledge loss.

Keywords: Computer-aided design (CAD), Annotation classification, Annotation representation rule, Model Knowledge Base (MKB)
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1 INTRODUCTION

Industrial organizations are facing an increasingly competitive market environment. Modern manufacturing enterprises are more inclined to use collaborative design and model reuse to improve product quality, reduce cost, and shorten product development time [1, 2]. However, poor data quality management is a serious obstacle to CAD model reuse [3]. Due to the lack of original design data and knowledge, typically, only the original designer can successfully trace the design knowledge context of the model [4]. At present, design team members of small and medium-sized enterprises still rely heavily on consulting colleagues and experts to obtain past design knowledge [5]. As we all know, a large amount of product data is never recorded; it is only stored in the minds of individuals. Product data includes not only three-dimensional models or simulations in CAD but also design knowledge generated by designers in the design process. It is essential to make design knowledge well-documented and easily accessible [6].

However, the increased mobility of individuals in industrial organizations means that those with the required design knowledge will not have easy access to consultation in the future. In order to retrieve the necessary information, it must have been captured and stored - formally stored in an external repository [7]. If the constructed 3D model is embedded with design knowledge representing its developers, it can improve people's understanding of the product and better reuse the product model [8]. Therefore, recording design knowledge in the form of annotations on corresponding parts or subassemblies (collectively called components) in CAD software is an effective mechanism for conveying design knowledge.

From a software development perspective, most CAD vendors have developed specialized tools [9, 10], such as the SolidWorks MBD plug-in, to manage CAD annotations and support model-based annotation practices. Adding annotations provides an opportunity to promote downstream processes, and the use of 3D annotation methods has been the basis for implementing Model-Based Initiatives in many companies. CAD annotations are divided formally into text data and structured data. Structured data is typically annotated by the dimensioning module in CAD software, and text data is annotated by the annotation module [5]. In fact, structured data can also be expressed as text annotations. 3D annotations allow design knowledge and rationale to be shared with other users directly through the 3D model, like the way that software engineers and programmers annotate source code [12]. This ensures that the design intent and design principles are preserved within the company and not limited to specific designers. However, the lack of standardized representation rules for annotations, especially text annotations, cannot restore the designer's fundamental design ideas, which results in inaccurate retrieval.

Generally, the research based on CAD software focuses on capturing the design intent, which is considered the application and selection of features when designers model. In the future, design intent can be captured by algorithms, but capturing designers' design experience and implicit knowledge is still a challenging problem [13]. Designers usually add 3D annotations to CAD software to avoid adding more applications to their daily work while keeping the information consistent with the geometric representation of components [14]. Poorkiany et al. [14] argued that the best approach for most companies is to seek seamless integration of knowledge storage tools and CAD software to avoid duplication of effort and the need to maintain multiple systems. At the same time, the tool should be easy for users to understand and use, with little disruption to the design process, which is ideal for many companies.

Therefore, in this study, the design knowledge of 3D geometric objects is used as annotation content, which formally includes text annotations and hypertext links, and the anchor points of annotations are components with additional annotations. Based on text annotations, annotation classification, and representation rules are defined. In addition, the knowledge base, MKB, has been developed to capture design annotations automatically. Compared with existing commercial CAD software, the MKB system is capable of parsing annotations and models. Based on the product design lifecycle, MKB is divided into three modules: conceptual design, detailed design, and manufacturing. These modules are used to manage design knowledge centered around models at different stages and store it in cloud databases, enabling knowledge sharing within teams or organizations.

The remainder of this paper is organized in the following manner. In Section 2, the relevant theoretical background is summarized. Section 3 defines annotation classification and representation rules and introduces details of the system's construction and implementation of MKB. Section 4 validates the proposed MKB system through two-stage investigation and research. The conclusion and further research are described in Section 5.

2 RELATED WORK

2.1 Design Knowledge

Engineering designers differ from other professionals in that they can apply technical knowledge, make decisions, and take action plans to solve design problems. This ability can also be referred to as “knowledge”, which is the intellectual asset of the enterprise and should be well cared for by the design organization [16]. From the dimension of the existing form, design knowledge is divided into explicit knowledge and tacit knowledge. In this article, explicit knowledge refers to information that exists in the form of text, images, videos, etc. and can be disseminated, shared, easily obtained, and managed (such as 3D models, simulation results, etc.); Implicit knowledge refers to personal knowledge and experience that exists in the designer's mind and can only be obtained through the designer's subjective expression, such as understanding design problems and specifying solutions based on design problems. However, no matter which method of knowledge management is used, the capture, representation, and retrieval of knowledge are of great importance [17].

From the essential dimension of product design, product design is the process by which the designer applies design principles to record design intent through interaction with CAD software. Hou et al. [18] defined design knowledge as the intellectual elements hidden behind the product model, such as design intent, reasoning, decisions, and options. Camba et al. [12] distinguished between design intent and design principle. Essentially, they defined design intent as the operation method provided by CAD systems and design principles as the motivation for designers to choose specific methods. Jones [19] developed a comprehensive classification system based on physical design models for managing design knowledge in the new product development process. For example, the topmost level is split into four dimensions: Purpose, Structure, Metadata and Measured properties. The Purpose branch of the taxonomy includes Intent, Category, Audience, Environment and Requirements dimensions. From a product lifecycle management perspective, Sudarsan et al. [20] believed that design information should be handled from the first conceptualization to the last instance, which has the characteristics of diversity and complexity. In fact, there is no uniform division and standard of design knowledge [21].

Design experts first formalize their knowledge and then transform it into features and parameters (topology, location, direction, size) or information [22], combined with the 3D model of products and finally stored in the knowledge base. The KBE system provides flexibility in storing both geometric and non-geometric product data [16]. However, 3D models are the core data in MBD, and traditional CAD software can provide some advantages for geometric modeling. Some KBE frameworks being implemented into CAD systems have become a trend. To transfer knowledge between CAD and KBE, Schätzle [23] used the STEP standard to transfer design intent elements and import the STEP files into the KBE framework AML.

Multiple researchers [24, 25] have captured the designer's design intent by monitoring the SolidWorks modeling process. Using natural language technology, Cheng et al. [1] transformed the captured design history into text descriptions. The purpose of design intent is to modify and reuse models, but it does not positively impact the designer's ability to generate new product design ideas. At the same time, the accumulation of design principal records will increase the difficulty of knowledge retrieval.

The Design Rationale Editor (DRed), developed by the Engineering Design Center (EDC) at the University of Cambridge and owned by Rolls-Royce Plc, allows engineering designers to document and use design rationale [26]. Bracewell et al. [7] used a real design example from a large aerospace company to test the tool's primary functions. Wang et al. [17] developed an efficient design knowledge retrieval method by utilizing DRed to create design principal records called DRed diagrams. Based on the DRed path, Kim et al. [27] proposed a method and developed a prototype system to integrate into DRed. This method can utilize the available context in the design environment to better understand the designer's information needs and intelligently recommend the next possible element to the designer.

Computer records, by contrast, can provide precise information, but often lack high-level semantics [11]. For example, CAD provides the assembly layout and detailed component dimensions. However, this type of information is only valuable for designers who already have some knowledge of the design and wish to see it in more detail. Knowledge acquisition is the most time-consuming process and is also the bottleneck in building a knowledge-based system [28]. Therefore, it is the most direct and accurate for designers to record their design knowledge, which reduces the burden of acquiring tacit knowledge later.

2.2 CAD Notes

The ultimate goal of a product model-based definition (MBD) is to provide a complete representation and definition of the product without the need for additional documentation. MBD is a dataset that contains the 3D model and annotations that specify life cycle support data [15, 29]. In the context of a 3D model, annotations typically represent valuable but difficult-to-communicate information (such as dimensions, descriptions, or manufacturing information) in other ways to enhance the geometry [21]. The function of annotations is to improve the designer's understanding of artifacts by specifying the representation of problems and solutions [9]. 3D annotations are typically represented as blocks of text anchored to specific parts of a 3D model. They are pointers whose purpose is to direct the viewer's attention to a specific area of the model [5]. Annotations are essential in design coordination and knowledge stimulation in the asynchronous phase [30]. Annotations can express and annotate information whose properties are not entirely geometric models, such as manufacturing processes, material types, function of components, etc. Annotated files are usually not public and can be used for multiple purposes, such as indexing information or remembering current design conditions [31].

Through experimental comparison, many researchers [32-34] have concluded that when critical design decisions need to be made about models, annotated models are more valuable than unannotated models in communicating design requirements.

Annotation can provide a form to describe the interaction between implicit and explicit knowledge and integrate implicit and explicit knowledge. Words mainly describe implicit knowledge to express design ideas. For unstructured annotations, Company et al. [9] further divided textual annotations into objectives, requirements, rationale, and intentions by function. Hisarciklilar & Boujut [31] proposed an annotation structure based on Speech Act Theory (SAT) and developed annotation tools to realize its semantic annotation function, which was used to express more complex information during design project review meetings. Lim et al. [35] proposed a method to form semantic annotation, which divided products into components and annotated the attribute information of components into product family ontology. This method is applied to new information sources in design and manufacturing repositories.

At present, the annotation function of most CAD software is usually provided by the product and manufacturing information (PMI) module, which is used to convey structural data, such as geometric dimensions and tolerances, surface finish, and so on. However, there is a lack of various forms of annotation storage and management. Hou et al. [18] proposed a construction method for a 3D explanatory model that integrated product geometric information, technical information, and design knowledge. The definition of design knowledge consists of design intent, argumentation, decisions, and solutions. A prototype system is established, and STEP 3D annotation model files and design knowledge XML files are parsed to construct a 3D explanatory model. Poorkiany et al. [14] built a prototype system installed in various software in extended form, which was used to customize the product design process. It can capture, construct, and access the design principles in different formats (such as CAD model, spreadsheet, text format, and web page). Plumed et al. [36] developed a voice annotation system that was fully integrated with CAD software. However, it is difficult to standardize the retrieval of voice description design knowledge and realize knowledge reuse, especially for companies that may store a large number of design schemes. Huet et al. [37] proposed a context-aware cognitive design assistant embedded in CAD software that constructed the design rules, contextual information, and tacit expert knowledge into a computable knowledge graph and stored it in the constructed design assistant. Camba et al. [5] proposed a 3D annotation management software tool that can filter annotations based on various standards such as content keywords, features, creation dates, etc. This tool works as a plug-in to SolidWorks. They designed a controlled study that recorded feedback from four group participants on different annotation mechanisms, believing that plugin tools for managing 3D annotations have promising development prospects in interacting with users.

CAD software has too many annotations on the same plane, making it difficult for designers to keep track of the critical points and increasing design time. Changing the view is easy to confuse. Wang et al. [17] argued that designers tended to consider problems and solutions before looking at solid models or process specifications in detail. As a result, standalone applications can manage models and annotations while allowing designers to prioritize design inspiration. Patel et al. [29] proposed a framework for building multi-layer annotations that used the annotations of different stages of the product life cycle through the stand-off (external or reference) method, allowing markup information to be stored separately and linked back to the model through references or points. Based on stand-off and in-line annotations [38], Camba et al. [34] proposed the concept of extended annotations, where design information was represented internally in the 3D model and separately in external repositories. They established an annotation manager to effectively manage the information stored in these extended annotations. Nzetchou et al. [39] have developed a VAQUERO demonstrator to demonstrate using OntoSTEPAP242 for CAD semantic annotation. This system allows the enriching of the semantics of low-level 3D models from the semantically rich STEP AP242 standard. Sandberg et al. [40] proposed a knowledge capture and sharing application during product development in a CAD environment. The system can add design principles to 3D annotations performed by designers, enabling simultaneous design and documentation. All product-related information is captured, tracked, and contextualized in the CAD design environment. However, this method does not classify annotations and cannot extract the required information efficiently, making it suitable only for parts. Boujut & Dugdale [30] described a 3D annotation tool that supported collaborative design, where multiple roles in a project collaborated on annotations at different design stages and ultimately used them for project review.

The introduction of annotations into the 3D model is an effective way to supplement design knowledge. However, too much annotation content or changing views leads to confusion about the annotation interface and difficulty in knowledge reuse. In addition, 3D models in a fixed view often have some invisible and hidden structures, so they cannot be annotated. To solve the above two problems, this paper adopts the exploded view module of CAD software (SolidWorks) combined with an annotation function. In this paper, we describe and evaluate a module of MKB that captures and stores 3D model annotations, primarily applied to 3D models during the detailed design phase. The design knowledge annotated on the model includes manufacturing information, material description, etc. Also, it includes hyperlinked files (such as simulation results, control programs, etc.) to realize effective communication and interaction with manufacturing departments.

3 ANNOTATE RECOGNITION AND STORAGE SYSTEM

3.1 Suggestions for Annotation Classification

One limitation of knowledge reuse in an enterprise is the lack of a shared foundation. Cross-company product development, even within a single company, almost always takes place in heterogeneous software environments. Therefore, there is a great need to support the formal representation, capture, and exchange of all information generated and used in the product development process, not just the final product representation. The ability to effectively and formally capture other types of information will become a vital issue [41]. Annotated 3D models can provide detailed instructions for the review stage or specific downstream operations (such as manufacturing planning, production simulation, and material procurement).

Model annotation standards such as ASME Y14.41-2003 and ISO 16792 distinguish among five types of annotations: dimensions, tolerances, symbols, notes, and text. From the perspective of annotation content, Company et al. [9] believed that annotations can be divided into two categories: symbols and plain text. Wherein the text annotations are mainly divided into objectives, requirements, rationale, and concepts. CAD annotations, a design supplement to 3D models, primarily aim to improve readability and comprehension. In our view, the annotation with components as anchor points can play a more positive role in interpreting and complementing them. Otherwise, excessive annotation content displayed on the CAD software interface can lead to confusion in the annotation interface, making it challenging to capture the necessary design knowledge.

Annotations are usually inserted as textual notes or comments but can also adopt other forms such as images, audio, etc. [34]. To simplify the annotation interface, we divide annotations into two forms: text and hypertext links. Notably, embedded hypertext links can be added to CAD software annotations, pointing to the Internet, local network, or files on the local hard drive. These files include simulation results, calculation processes, and various file formats of the design.

The detailed design phase is the core of mechanical design. Designers use mechanical principles and engineering knowledge to create detailed drawings and models, including detailed information on dimensions, shapes, materials, and processing techniques, and to ensure the accuracy and feasibility of the design through simulation. Based on the characteristics of the detailed design stage, we group text annotation content into seven categories: Geometry, Material, Connection Method, Dependency Relationship, Working Mode, Function, and Model Selection. For example, geometry includes dimensions, dimensional tolerances, surface roughness, and so on. To represent design knowledge concisely and accurately, Table 1 lists annotation classification and representation rules for text annotations by syntactic regulations [42]. For example, "B of (preposition) A is X" represents the syntax rules of geometric data, "tuple (B, A, X)" represents the keyword tuple in the sentence, and "component-NN (A)" means "A" as a component noun. Table 2 illustrates the relevant symbols involved in the representation rules.

Annotation		*Representation Rules*	*Example*
Text Annotations	Geometry	B of (PRP) A is X → tuple (B, A, X) ∩ component_NN (A) ∩ component_attribute_NN (B) ∩ number_CD(X)/material_NN(X)	The diameter of the outer ring is 18mm.
	Materials		The material of the double helix is 201 stainless steel.
	Connection Method	The connection method between A1 and A2 is Y→ tuple (A1, A2, Y) ∩ component_NN (A1) ∩ component_NN (A2) ∩ connection_VVD(Y)	The connection method between the discharge port and the feed bin is welding.
	Dependency Relationship	A include C→ tuple (A, C) ∩ component_NN (A) ∩ subcomponent_NN (C)	The top cover includes the feeding port and observation port.
	Working Mode	A1 drive A2 to Z → tuple (A1, A2, Z) ∩ component_NN (A1) component_NN (A2) ∩action_VVB(Z)	The motor drives the conveyor belt to rotate.
	Function	A1 V A2→ tuple (A1, V, A2) ∩ component_NN (A1) ∩ component_NN (A2) ∩action_VVB(V)	Distribution box support frequency converter.
	Model Selection	A: W→ tuple (A, W) ∩ component_NN (A) ∩model_CD(W)	Motor: QABP-180M6A
Hypertext Links		www.website.com/ "C:\Users\Desktop\XXX.xlsx"	

Table 1: Annotation classification and representation rules.

Symbol	*Explanation*
component_NN	component noun
component_attribute_NN	component attribute noun
number_CD(X)	cardinal number
material_NN(X)	material noun
connection_VVD(Y)	connection method participle
subcomponent_NN (C)	subcomponent noun
action_VVB(Z)	action verb
model_CD(W)	model

Table 2: Relevant symbols involved in the defined representation rules.

The annotated object for this article is a 3D model of the overall unit design, including the power system, transmission system, executive system, and control system [44]. Typically, the power and control devices are shown schematically in the 3D model. Other stakeholders cannot obtain detailed information from the model, such as the control system's control program, motor selection, and so on. Trying to piece together a complete picture from loosely organized folders, from formal reports and CAD drawings to rough notes and sketches, is both difficult and time-consuming [7]. Taking the design of a uniform feed mixer as an example, using the presentation rules in Table 1, Appendix 1 lists all annotated content added to the 3D model shown in Fig. 1. In SolidWorks software, the actual path of the hypertext link embedded in the annotation is not displayed in the annotation text. Annotations for hypertext links are displayed in blue.

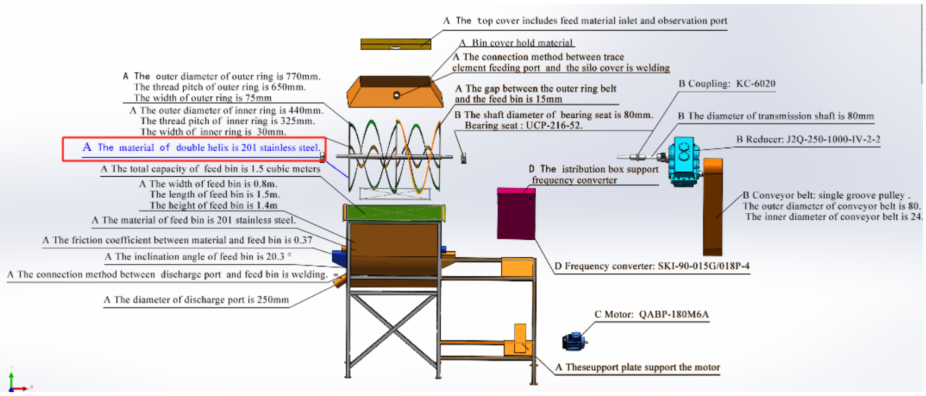

Figure 1: Example of 3D model annotation.

3.2 Construction of MKB System

Wang et al. [17] believed that design engineers tend to look for knowledge about specific problems and solutions before they decide to look at detailed CAD models. Piegl [43] suggested that the Internet will promote the reuse of CAD components, especially the networking of computers and access to databases. As Patel et al. [38] believed, offline annotation offers more incredible benefits than online annotation for using CAD models, especially when data needs to be shared. Therefore, this article tightly integrates design knowledge and models, stores them offline in MKB, and achieves knowledge sharing among relevant stakeholders through the cloud.

To intelligently parse and store design knowledge using Visual Studio, MySQL, and MongoDB, we developed a Model Knowledge Base (MKB). The MKB client, as a standalone program, calls the SolidWorks API to read models and annotations. It can also use a third-party open-source interface, NPOI, to parse .xlsx files. The main structure of the system is SolidWorks - Client - Cloud Database, and Fig.2 shows the functions of the client and cloud database and the connections among the three.

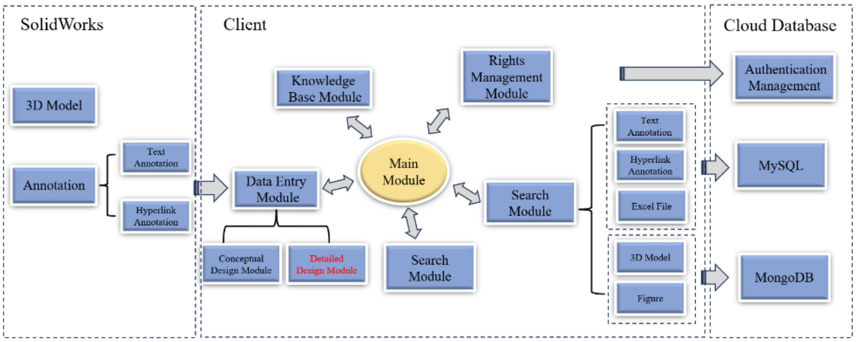

Figure 2: System framework with MKB.

The interface of the MKB system is divided into two parts: database query and data entry. The system is designed to manage product lifecycle data, with each part including three modules: conceptual design, detailed design, and manufacturing. In another research, the conceptual design module has been disclosed. It should be noted that the annotation content of the three modules is not fixed. In this case, the geometric annotation content, including dimensional tolerances and surface roughness, is related to the processing capability of the factory. Therefore, this part is jointly determined by the designer and the factory and is included in the MKB manufacturing module. This paper introduces the data entry and query of the detailed design module. In fact, the tool is rendered in Chinese. An English interface version is shown in Fig. 3 to be easily understood.

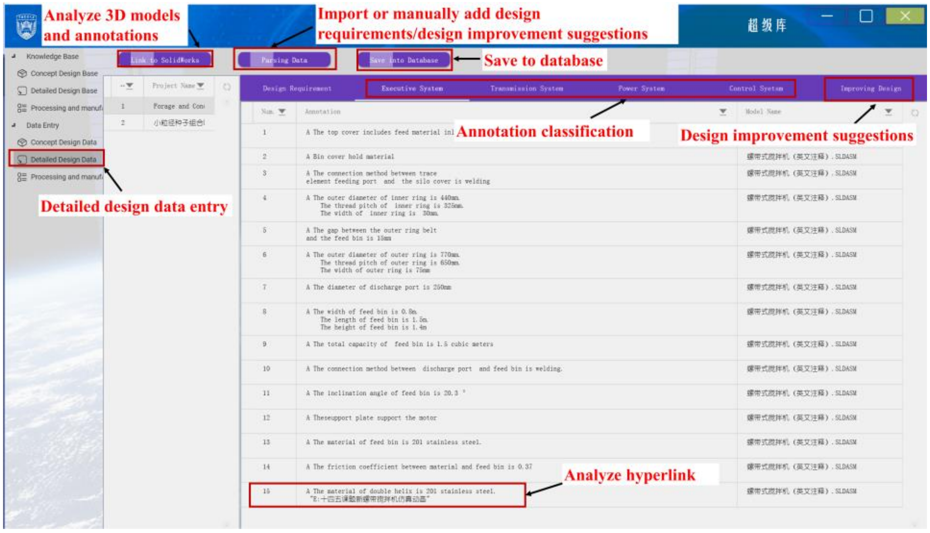

Figure 3: Detailed design data entry module interface.

First, the user creates a new project under the detailed design entry module, using a uniform feed mixer as an example. The design requirements were saved in advance in the .xlsx file; click the " Parsing Data " tab, the .xlsx file can be parsed and then saved in the sub-module "Design Requirement". Clicking the "Link to SolidWorks" tab allows the MKB system to automatically read the currently active model and its annotations in SolidWorks by calling the SolidWorks API. The detailed design module of MKB divides annotations into four sub-modules (executive system, transmission system, power system, and control system) based on the overall system classification to facilitate retrieval and management. The system can recognize the tags made in text annotations and categorize them into corresponding submodules. For example, the annotation with the first word "A" is classified into the "Executive System" submodule. The "Save into Database" function can store annotations, models, and hypertext link files in a cloud database. To make it easier for different stakeholders or reviewers to provide design improvement opinions, an "Improving Design" tab is added to this module, and users who pass authentication can add design improvement opinions. After completing the project, it can be easily published online using cloud services. As new improvement opinions or design knowledge are generated, all activities are updated simultaneously in software. Interactive communication allows engineers to examine the potential impact of their decisions on manufacturing based on relevant evidence, even if the engineers are not in the same location.

Another key feature of our system is the ability to search for text comments or links, and the search function is set in the "Detailed Design Base" module, as shown in Fig.4. It can also filter the content of different attributes. For example, all links can be filtered out, and only text comments can be displayed. The user allows multi-level retrieval, as shown in Fig.5. For example, users can retrieve related items by entering their keywords and then adding search fields to retrieve comments for specific keywords under that item. Search results are displayed in the comment table position of the module interface.

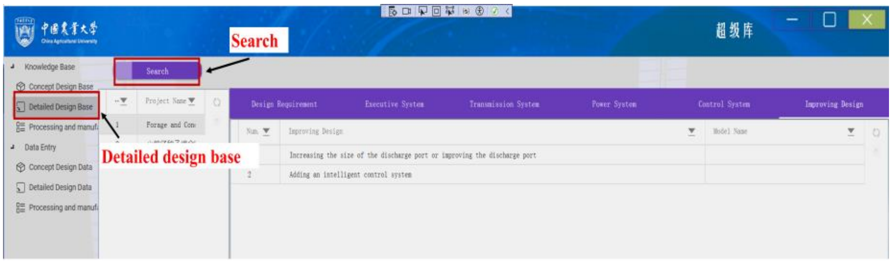

Figure 4: Detailed design base module interface.

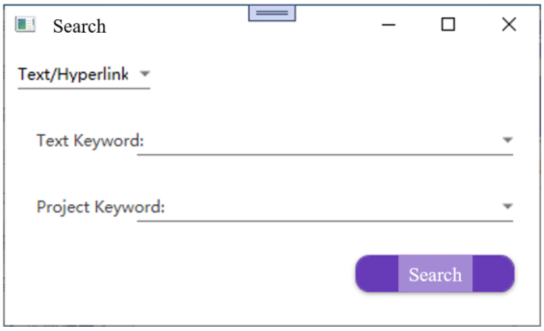

Figure 5: Search interface

The ultimate goal of any knowledge management research is to effectively reuse knowledge without putting too much burden on designers. In our model, designers can use CAD software to annotate 3D models and use MKB to automatically capture and store design knowledge without spending valuable time managing other software.

4 EXPERIMENTAL STUDY

The main criterion for measuring the likelihood of software success is not quantitative calculations but rather whether designers will continue to use the tool because it helps or at least does not hinder their daily work. To validate the proposed MKB system, we conducted a one-hour training and practice seminar for 50 designers and researchers. All participants already have a solid foundation in using SolidWorks or other CAD software packages. Designers are required to annotate their 3D model during the practical phase, use MKB to parse and store it in the software, and then add review comments to the models and design knowledge uploaded by other participants in the software.

50 participants were divided into two groups. The first group (20 designers) received a questionnaire within a week of training. The survey questionnaire was designed based on Kirkpatrick's evaluation method [45], which is divided into four levels: (1) Response: evaluating the satisfaction level of the trainees; (2) Learning: measuring the learning acquisition degree of the trainees; (3) Behavior: examining the knowledge application level of the trainees; and (4) Result: calculating the economic benefits of the training output.

15 questionnaires were actually received, with three designers exceeding the survey time limit. Two team managers gave feedback face-to-face, believing MKB can effectively manage designers' design intentions. As managers, they have really felt the frequent turnover of personnel, especially in recent years, which has further hindered subsequent projects. They believe that MKB integrates design knowledge generated by different divisions of labor in the project and strengthens collaborative design. Besides, a manager suggested adding more interactive features to the software, such as assigning tasks, checking task progress, and so on.

According to the results of the survey questionnaire, the evaluation of four levels of the Kirkpatrick Model is described here:

Response: Only 1 out of 15 designers expressed reluctance to use MKB, believing that the software would increase their workload. He also pointed out that the lack of specialized usage specifications, e.g., component names, makes it difficult to reuse knowledge in the future. Some designers stated that before the training, they did not know that hypertext links could be added to annotations and believed that more useful information could be shared through hypertext links, which could reduce the cost of communication among designers.

Learning: All designers believed that the MKB interface classification was clear and after one hour of training and practicing, they had become proficient in operating the MKB system.

Behavior: Many designers believe MKB will be convenient for their future work. One of the engineers who made design improvements expressed great willingness to use this software because he found a 2014 design plan as a reference, but he did not know why the designers at that time made such a design plan.

Result: The designers generally believe that MKB can enable new personnel to quickly understand the product, achieve technical inheritance and iteration, and accelerate project development progress. Simultaneously, data sharing is beneficial for collaborative design and improves the efficiency of team collaboration.

Given that the first stage of investigation is mostly subjective, the analysis process is difficult and time-consuming, and the results are not easy to analyze quantitatively. The analysis results showed that some non-verbal respondents were unable to clearly express their true thoughts, resulting in some worthless answers. Therefore, the retrieved answer sheets were subjected to natural language processing using Python; the process sequentially included word division, deletion of deactivated words, synonym replacement, extraction of nouns and adjectives, calculation of word frequency, and creation of a word cloud, shown in Fig.6. According to the word cloud, we can see that the functional aspects that the researchers are more concerned about include "interface", "retrieval", "storage", etc., and the performance aspects include "efficiency", "fluent", "conservative", "speed", etc.

Developing the MKB issues in the word cloud, a survey questionnaire was created using a five-point Likert scale (strongly agree, agree, neutral, disagree, strongly disagree) to evaluate the usability of the MKB system and user satisfaction with the tool from three aspects. The questions given to the second group participants who have been using MKB for a month and the statistical measures used to analyze the results are shown in Table 3.

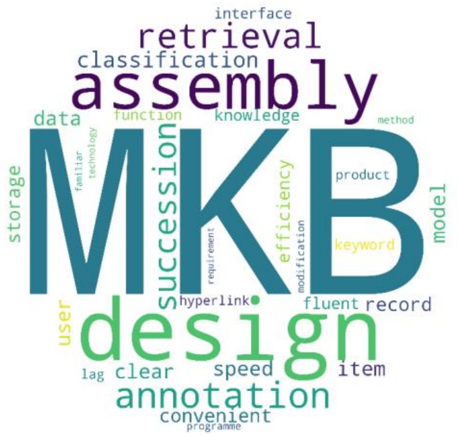

Figure 6: Word cloud results

Question	*Scale*	*Mean*	*Std.Dev*
Overall Reactions to the Software			
Overall experience with the MKB	0(terrible)-5(wonderful)	4.53	0.63
Value of the MKB	0(not value)-5(very value)	4.5	0.51
Level of interest in using the MKB	0(dull)-5(stimulating)	3.9	0.76
Ease of use	0(difficult)-5(easy)	4.33	0.76
Screen			
The clarity of the interface	0(confusing)-5(very clear)	4.07	0.78
Rationality of classification	0(unreasonable)-5(very reasonable)	4.37	0.56
Highlighting of search results	0(not at all)-5(very much)	4	0.69
System Capabilities			
System smoothness	0(lag)-5(fluent)	4.2	0.66
System stability	0(unstable)-5(stable)	4.23	0.63
Reliability of linking with other software	0(unreliable)-5(reliable)	4.03	0.67
Correcting your mistakes	0(difficult)-5(easy)	4.4	0.62
The speed of data entry	0(slow)-5(fast)	3.87	0.86
The speed of data retrieval	0(slow)-5(fast)	4.5	0.57

Table 3: User satisfaction questionnaire and results.

Overall, MKB's experience and value scores are particularly high, and researchers have given positive feedback and acknowledged its value. Regarding the " Level of interest in using the MKB" issue, most researchers were concerned that annotation would take longer, increase the daily workload, and have a shorter usage time. They have not yet fully used it to solve practical problems but will continue to use this system. It is worth noting that the lower score given to the question: “The speed of data entry”, and the upload speed is slow due to the complexity of the models uploaded by some researchers, with many sub-assemblies and parts.

The application prospects of MKB have been demonstrated through a two-step investigation. MKB can parse the design knowledge and hypertext links annotated on the model and upload them to the cloud database for knowledge sharing. This method allows all knowledge generated based on the model to be stored within the organization, rather than tied to the designer himself.

5 CONCLUSIONS AND FURTHER WORKS

To improve the design knowledge to guide downstream processing, manufacturing, procurement, etc., in 3D models, this study described a text and hypertext link annotation pattern representing design knowledge in a 3D model. A cloud-based MKB system is developed that can analyze models and their annotations to capture and save design knowledge.

Specifically, in our research, CAD annotations are presented in richer forms, with the aim of integrating design knowledge with 3D models. We distinguish two types of annotations: text annotations and hyperlink annotations. In terms of managing text annotations, we define representation rules that facilitate knowledge retrieval and understanding.

Our software focuses on the knowledge of the overall unit. In the detailed design module, the parsed model and its annotations are divided according to the device structure (power device, execution device, control device, transmission device) and saved in different submodules. Setting up submodules provides clearer management of annotation content in the MKB system, making it easier for stakeholders to find the design knowledge they need. By uploading data to the cloud database, knowledge sharing within the group or enterprise is achieved. At the same time, Design Requirements and Design Improvement submodules are added to the Detailed Design module to provide opportunities for stakeholder interaction.

Our investigation confirmed the feasibility of extending annotation content in multiple forms and the value of using MKB to manage design knowledge. Some researchers believe that annotations will increase their workload, but they see remarkable promise and value in MKB and are willing to continue to use and promote it. In our view, text and hypertext links can add richer design knowledge to 3D models, ensuring that subsequent designers can quickly understand the context of the product design in the early stages of the product development process and make more informed decisions for design improvement.

In our research, the annotated anchor points are usually components (combinations of parts) that are not standard parts, so they lack consistent naming standards. Our system categorizes components by manually adding markers in annotations to classify corresponding annotations into submodules. In the future, we will focus on establishing a set of component standards through cooperation with enterprises, and automatic identification of component categories can be achieved based on component standards.

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Appendix 1 Annotations of a uniform feed mixer

Mechanism	Annotation
Executive System (A)	The outer diameter of the outer ring is 770mm. The thread pitch of the outer ring is 650mm. The width of the outer ring is 75mm.
	The outer diameter of the inner ring is 440mm. The thread pitch of the inner ring is 325mm. The width of the inner ring is 30mm.
	The material of the double helix is 20l stainless steel.
	The total capacity of the feed bin is l.5 cubic meters.
	The material of the feed bin is 201 stainless steel.
	The friction coefficient between the material and the feed bin is 0.37.
	The inclination angle of the feed bin is 20.3°.
	The connection method between the discharge port and the feed bin is welding.
	The width of the feed bin is 0.8m. The length of the feed bin is 1.5m. The height of the feed bin is 1.4m.
	The diameter of the discharge port is 250mm.
	The top cover includes feed material inlet and observation port.
	Bin cover hold material.
	The connection method between the trace element feeding port and the silo cover is welding.
	The gap between the outer ring belt and the feed bin is 15mm.
	The support plate supports the motor.
Transmission System (B)	The shaft diameter of the bearing seat is 80mm. Bearing seat: UCP-216-52.
	Coupling: KC-6020.
	The diameter of the transmission shaft is 80mm.
	Reducer: J2Q-250-1000-1V-2-2.
	Conveyor belt: single groove pulley. The outer diameter of the conveyor belt is 80mm. The inner diameter of the conveyor belt is 24mm.
Power System (C)	Motor: QABP-180M6A.
Control System (D)	Frequency converter: SKI-90-015G/018P-4.
	The distribution box supports a frequency converter.

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