A Smart Conflict Resolution Model using Multi-layer Knowledge Graph for Conceptual Design

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Abstract

Reducing the impact of conflicts on requirement-function-structure mapping in the early stage of product design is an important measure to achieve conceptual innovation, which relies on accurate reasoning of multi-domain knowledge. As product requirements become more personalized and diverse, traditional discrete knowledge organization and reasoning methods are difficult to adapt to the challenges of continuity and precision in conceptual solution. Knowledge graphs with complex networks have obvious advantages in association detection, knowledge visualization, and explainable reasoning of implicit knowledge, which offer innovative opportunities for conflict resolution in conceptual design. Therefore, a smart conflict resolution model using a multi-layer Knowledge Graph for Conceptual Design(mKGCD) is proposed in this study. A knowledge expression form of FBS-oriented design patent vocabulary is proposed, which is used for knowledge entity recognition and relation extraction based on natural language processing. A label mapping method based on inventive principles is used for patent classification and a four-layer semantic network for conflict resolution is constructed. Through semantic distance calculation, the designer's requirements for function/behavior/structure are smart deployed to obtain appropriate knowledge. A case study of the conceptual design of a collapsible installation and handling equipment demonstrates the feasibility of the proposed approach. The proposed method can not only meet the functional solution and innovation in the context of different design requirements, but also effectively improve the design efficiency in the iterative design process by means of multiple meanings of one graph.

Keywords: Knowledge Graph; Conflict Resolution; Conceptual Design; Inventive Principle; FBS

1. Introduction

Conceptual design is the stage that ensures product features meet user needs, which is the most important stage in the product development process[1-3]. Through many-to-many mapping, it can sequentially transform user requirements into functional requirements and specific physical structures[4]. The solution of the conceptual scheme is often accompanied by the generation of conflicts. This is a phenomenon that to improve or realize a certain feature of a product, other functions or performances are deteriorated, and it includes physical conflicts and technical conflicts[5]. Conflicts, once created, will have an irreparable impact on the product, so conflict resolution is an essential part of conceptual design[6].

Conflict is characterized by continuity and diversity[7]. Continuity means that conflict affects multiple layers of the function-behavior-structure mapping, that is, the conflict generated in one layer affects the next layer. Diversity describes that conflicts between function, behavior, or structure layers are emergent and variable. Researches on how to judge and mitigate conflicts have achieved some results. Most of these methods are inversely derived from the results of the scheme, and achieve functional balance by modifying local structures, but they are not conducive to timely tracking and solving conflicts in the design process. With the continuous development of information technology and knowledge engineering technology, it has brought new solutions to product conceptual design and complex conflicts. TRIZ theory occupies an important position in the field of innovation design with its systematicity and practicality[8-9]. Conflict resolution is the core content of TRIZ theory. The conflict matrix establishes the connection between the parameters that generate conflict and the inventive principle, which provides guidance for conflict resolution. The conflict matrix table is shown below.

Table 1 Correspondence table of parameters and inventive principles[8]

Worsening parameter / Improving parameter	1	2	10	11	….	39
1 Weight of moving object	…..	…..	8,10,18,37	10,36,37,40	…..	3,24,35,37
2 Weight of stationary object	…..	…..	8,10,19,35	10,13,18,29	…..	1,15,28,35
…..	…..	…..	…..	…..	…..	…..
39 Productivity	…..	…..	10,15,28,36	10,14,37	…..	…..

The diversity of knowledge and the efficient knowledge reasoning of knowledge graphs provide multiple opportunities for product conceptual design, it supports designers in generating inspiration and designing a wide range of innovative schemes. Many scholars help designers organize design resources and improve design efficiency by building knowledge systems, but how to use a highly integrated cross-domain knowledge reasoning mechanism to assist conflict resolution in the conceptual design stage is not very targeted. Knowledge graph technology integrates and associates knowledge through the structured network, and can effectively push cross-domain heterogeneous knowledge through complex reasoning methods, providing new opportunities for conflict resolution and design innovation. At present, it is a challenge to construct an integrated knowledge graph that satisfies the conflict matrix and the inventive principle through natural language processing and smart reasoning technology based on the mapping features of function-behavior-structure.

At present, some knowledge graphs or complex networks have been proposed and verified to be effective for divergent design thinking and auxiliary solution innovation. Further, to build a knowledge graph and its smart reasoning system for conceptual design and conflict resolution, there are two main challenges: 1) How to clearly express the function, behavior, structure, and internal relationship of cross-domain patent knowledge through a networked structure; 2) How to integrate classic conflict resolution theory with knowledge graph, and effectively push functional and structural cases to assist conceptual design through smart reasoning technology. To overcome these problems, a smart conflict resolution model that integrates conflict resolution into the intelligent design process was proposed. This study is to assist designers in the conceptual design process in the form of software and methodologies. It builds a four-layer semantic network to establish connections between function, behavior, and structure, assign respective inventive principle labels to patents, and finally use conflict matrices to help designers filter for conflict-free design inspirations.

The study is organized as follows: A review of related studies is present in Section 2. A framework of the proposed model is presented in Section 3. Section 4 introduces the main methodologies in the framework, including knowledge entity recognition and relation extraction technology based on natural language processing and FBS, and knowledge reasoning technology based on semantic distance calculation. Section 5 describes the application of the proposed framework and methodology in the design of a collapsible installation and handling equipment. The discussion and conclusion are presented in Section 6 and Section 7, respectively.

2. Related Work

2.1 Knowledge-based Design

Knowledge-based design (KBD) is the intelligent design that organizes and reuses knowledge to help designers upgrade their products. Several previous studies have been conducted on knowledge-based design. Dong M et al. proposed a knowledge-based interactive design recommendation system that iteratively interacts virtual product displays with designer expertise to find the best design solution[10]. Long X et al. proposed a knowledge-based automated design system for mechanical products that enables case-adaptive automation without expert involvement[11]. Francalanza E et al. propose a tool for designing cyber-physical production into a knowledge-based tool that can assist engineers in dealing with the unpredictability of product evolution[12]. Akasaka F et al. proposed a knowledge-based design support system for product service systems and developed a prototype CAD system that can support new design solutions by integrating previous knowledge[13]. Chen Y et al. propose a knowledge-based framework for creative conceptual design of multidisciplinary systems[14]. Feng H et al. constructed a knowledge-based and extensible aircraft concept design environment (KEACDE), which enable designers to wrap add-on extensions and make their aircraft conceptual design systems[15]. Most of the previous studies have organized and utilized prior design knowledge and applied it to new design processes to facilitate designers' design activities and improve design efficiency, which illustrates the necessity of knowledge for design innovation.

2.2 Conflict Resolution in Conceptual Design

Conflict resolution is an important step to ensure the rationality of the product at the conceptual design stage. Some methods for conflict resolution have been proposed, such as Zhang R et al. proposed a conceptual design process model using functional basis and TRIZ as the enabling technologies[16]. The model compensates for the limitations of axiomatic design by integrating functional basis and TRIZ into the axiomatic design. Jenab K et al. proposed a conceptual design selection model considering conflict resolution, which not only resolves the conflict of experts' opinions, but also aggregates the layers corresponding to the decision criteria into a single graph[17]. Jing L et al. proposed a proposed conceptual decision model based on Dempster-Shafer (DS) evidence theory and intuitionistic fuzzy-Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR), which considers the fusion of ambiguity semantic variables[18]. Integrating design processes and conflict resolution methods through a structured design framework can help standardize the conceptual design process and improve design efficiency.

Delgado-Maciel J et al. proposed an approach combining TRIZ with system dynamics simulation to assist in the evaluation and simulation of conceptual design, which helps designers to identify conflicts and assists them in decision making[19]. Favi C et al. proposed a multi-objective design approach based on functional basis, modular heuristics and mathematical evaluation[20]. The above scholars' studies integrate and apply multiple design methods to conflict resolution, and these methods converge the design space and broaden the possibility of conflict resolution by combining multiple design methods. In addition, the effective application of these conflict resolution methods also requires organized knowledge reasoning and deployment mechanisms, and how to link these methods with design resources has become a new challenge.

Dhiman G et al. proposed a multi-objective seagull optimization algorithm, which introduces the concept of dynamic archiving and has the feature of caching non-dominated Pareto optimal solution[21]. Abualigah L et al. proposed a population-based optimization algorithm to find the optimal solution by converging the search space[22]. Dhiman G proposed a chimpanzee optimization algorithm based on Sine-cosine and Spotted Hyena, which overcomes the disadvantages of ChoA algorithm such as slow convergence and local minima[23]. Ahmadianfar I et al. proposed an optimization algorithm using the slope change logic calculated by the RK method as a global optimization mechanism[24]. The above research is carried out from the perspective of algorithms, through the improvement of algorithms to achieve further optimization of conflict resolution and decision evaluation. The studies of the above algorithms are more inclined to conflict evaluation and solution, and ignore the relationship between conflict resolution and design process.

On the other hand, there has been a lot of research directed at identifying the inventive principles used in patents from patent texts. The classification of patent texts by inventive principles is beneficial in providing rich examples for conflict resolution. Tong et al. proposed a new theme of automatic patent classification in the TRIZ category in 2006[25]. Immediately after that, the team classified 40 inventive principles into 22 categories in 2008, and tested and analyzed them with 674 patent documents[26]. They solved the multi-label classification and category imbalance problems. These studies have inspired the construction of smart conflict resolution model.

A method that uses functional decomposition and conflict resolution to support resilient conceptual design is proposed by the authors to provide resilience for redundant conceptual schemes that meet functional requirements[27]. Conflict resolution and decision evaluation in the conceptual design phase are beneficial to converge the design space, clarify design goals, and improve design efficiency. Most of the current research on conflict resolution focuses on conflict identification and resolution without linking conflict and knowledge, which makes it difficult for designers to cope with the diversity of conflicts if they only rely on their own knowledge. Therefore, it is necessary to combine cross-domain knowledge of actual cases with conflict resolution to help designers resolve conflicts by constructing a knowledge graph that correlates knowledge with cases.

2.3 Knowledge Graph in Conceptual Design

The richness and breadth of knowledge provides multiple design inspirations for product design[28-30]. Knowledge graphs organize and utilize knowledge effectively and play an active role in a wide range of industries, including materials, biology, manufacturing[31-33], and management.

Many scholars have conducted research on knowledge graphs in the field of conceptual design. Liu et al. proposed a functional-structural-conceptual network that enhances the connection between design information by integrating functional and structural information[34]. Wang K et al. propose a data-driven concept network based on machine learning to capture design concepts and meaningful concept combinations as useful knowledge by mining web documents and literature, which is further exploited to inspire designers to generate ideas[35]. Sarica S proposes a technical semantic network, the core of which is to guide the reasoning of new technical concepts around focused design areas to form new design ideas[36]. Jia J et al. proposed a design issue-solving oriented knowledge graph model, which enables the capture and reuse of implicit design knowledge[37]. Hao J et al. proposed knowledge graphs as a means to represent word-based cDSP formulations and facilitate fast navigation of target knowledge to support decision making[38]. Scholars have proposed different design knowledge systems from the aspects of knowledge organization, expression, and reasoning. The knowledge organization method represented by ontology technology has been proved to be effective for the management of domain knowledge. As innovation becomes the main requirement of design, a large amount of multi-domain knowledge is more and more critical for the divergence of designers' thinking, and how identifying and connecting knowledge in these different domains has become a complex problem in conceptual design.

Knowledge graphs in the field of conceptual design have significantly reduced the time and labor cost for designers to search for design knowledge by integrating a large amount of useful design knowledge, which has greatly facilitated designers' design work. These knowledge graphs utilize interdisciplinary and multidisciplinary knowledge to stimulate designers' innovation and ultimately facilitate the generation of solutions, but still have their limitations. First, existing design-oriented knowledge graphs are more concerned with the relationship between input keywords and output knowledge, but from the perspective of innovation, the authors also have to consider whether the output knowledge can solve the conflict problem. Second, conflicts should be resolved in the process, not at the end. Conflicts arising in the process should be identified and resolved early in the process of conceptual design of FBS mapping.

2.4 A Brief Summary

Conflict resolution for conceptual design of products has recently advanced. Knowledge facilitates beneficial assistance for conflict resolution, but traditional discrete knowledge organization and reasoning methods are difficult to adapt to the challenges of continuity and diversity of conflicts. Knowledge graph offer significant advantages in association detection of knowledge and interpretable reasoning of tacit knowledge, which provide innovative opportunities for conflict resolution. Applying knowledge graph to conflict resolution, several factors still need to be further considered:

(1)A structured design framework needs to be used to organize the relationship of the conceptual design process to conflict resolution methods and knowledge reasoning systems when conceptual solutions need to be innovative.

(2)Multi-domain knowledge, represented by patents, is the main resource that assists in mapping conceptual solutions from function to structure. Entity recognition and relationship extraction techniques need to be used to organize these resources and build knowledge graph.

(3)Adaptive knowledge classification and reasoning methods need to be used to improve the accuracy of knowledge graph pushing. If there are conflicts in the conceptual design process, these methodologies must satisfy both the user requirements for function or structure and the principles of conflict resolution."

Therefore, a smart conflict resolution model based on efficient organization of knowledge is needed to address these challenges.

3. A Framework to Support Conflict Resolution using mKGCD

The focus of this study is to propose a general and systematic smart conflict resolution model using mKGCD. The proposed framework of the proposed model is shown in Figure 1.

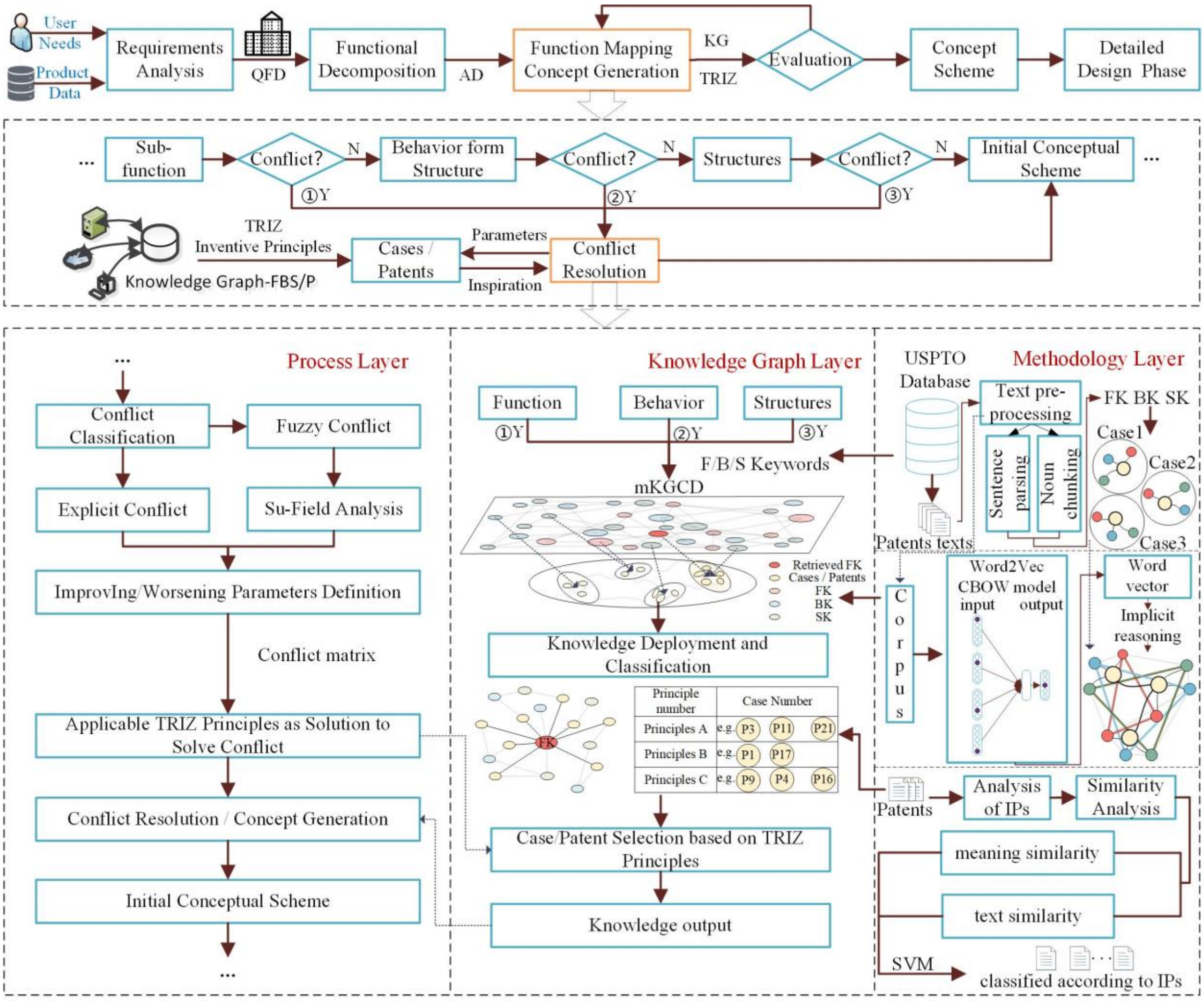

Figure 1. The framework of the smart conflict resolution model

Conceptual design starts with the analysis of user requirements and product data, and ends with the generation of conceptual schemes, which is the key process of design innovation. After requirements transformation and functional decomposition, the main tasks of conceptual design are functional solution, behavioral solution, and structural solution, and these three stages are often accompanied by conflicts, which bring uncertainties and limitations to the design results. The conflict solving method in TRIZ is applied in the proposed framework, which transforms different improvement and worsening parameters in engineering problems into inventive principles by conflict matrix. These inventive principles serve as a key in the framework to connect the design process and the knowledge system.

A knowledge system serving conceptual design not only needs to retrieve the patents/cases corresponding to the exact functions, behaviors, or structures, but also show the designers what innovative elements these patents/cases use to resolve conflicts. In particular, for multi-domain knowledge, a four-layer semantic network supporting conflict resolution is introduced in the framework through three steps, 1) Combined with Stanford parser extraction rules, the knowledge expression form of FBS-oriented design patent vocabulary is defined; 2) After denoising and sentence segmentation of the initial text using natural language processing techniques, entity recognition and relation extraction of subject-verb-object (SVO) for independent sentences are performed; 3) Categorizing inventive principles into new categories recognizable by SVM for automatic classification of textual information about inventive descriptions in patents.

4. Methodology

The patent-based mKGCD represents function knowledge (FK), behavior knowledge (BK), structure knowledge (SK), and patent knowledge (PK).

$$P \rightarrow \mathrm{G} = \langle E, R \rangle \tag{1}$$

$$E = \{FK, BK, SK, PK\} \tag{2}$$

$$R = \langle head\_k, rel\_type, tail\_k \rangle \tag{3}$$

$$\begin{cases} head\_k \in V = \{FK, BK, SK, PK\} \\ tail\_k \in V = \{FK, BK, SK, PK\}, \quad tail\_k \neq head\_k \end{cases} \tag{4}$$

$$\begin{cases} rel\_type = "having", head\_k \in PK \\ rel\_type = "belong", head\_k \notin PK \cap tail\_k \in PK \\ rel\_type = "mapping", head\_k \notin PK \cap tail\_k \notin PK \end{cases} \tag{5}$$

where E and R denote the set of nodes of the mKGCD and the set of relation between nodes, respectively; the set of nodes E contains nodes of four different knowledge types, FK, BK, SK, and PK, in total; *head_k* represents the head knowledge element in the relationship parses, which represents a specific design knowledge, and its knowledge type can be one of the four knowledge sets of FK, BK, SK and PK; *rel_type* represents the relationship between the head knowledge element and the tail knowledge element; *tail_k* represents the tail knowledge element in the relationship parses, and its knowledge type is different from *head_k*.

The large amount of knowledge contained in patents is very meaningful for innovative product design[39]. The mapping relationship between function, behavior, structure, and patent is shown in Figure 2. Taking the functional layer as an example, the organization of the functional layer relies on the functional concept ontology[40-41], and the links between functions are associated according to different design problems or different behaviors or structures. Function knowledge, behavior knowledge, and structure knowledge are the most important knowledge derived from patents, which in turn reflect the innovation and characteristics of the product. Extracting FK, BK, and SK from patents and organizing the various types of knowledge reflects a single mapping process of knowledge. However, as the number of patent texts increases, the mapping process changes from a single mapping process to a complex mapping process, which is attributed to the fact that different patents may take the same function and have different structures, or they may take different function and have the same structure.

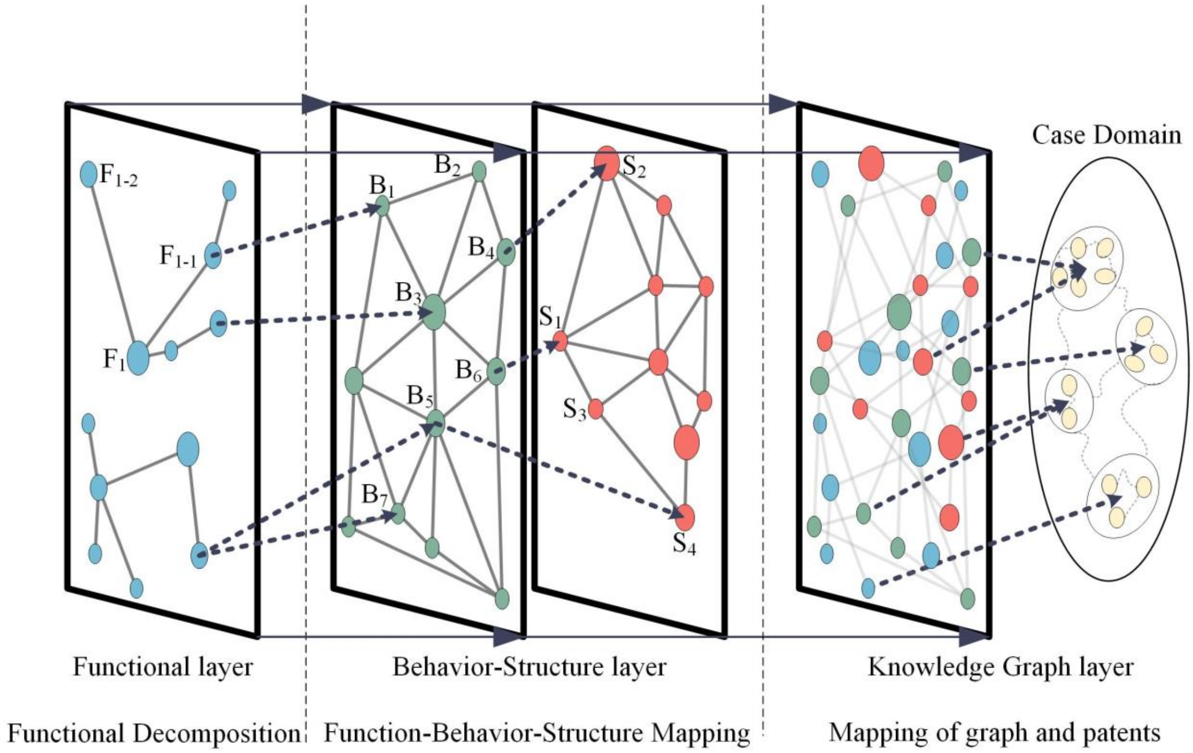

Figure 2. A function-behavior-structure-and patent mapping process

4.1 A Method of Knowledge Entity Recognition and Relationship Extraction Based on Natural Language Processing

Extracting FK, BK, and SK from patents is a complex and non-linear process. Previous studies have given function tables, behavior tables, and structure tables of FBS-based patent texts[39].

$$P \rightarrow \alpha = \left(F_v,\ F_n,\ F_a\right) \tag{6}$$

$$P \rightarrow \beta = \left(B_b,\ B_{pe},\ B_m\right) \tag{7}$$

$$P \rightarrow \gamma = \left(S_{sc},\ S_f,\ S_{gf},\ S_i\right) \tag{8}$$

Where, FBS based patent's function knowledge set α includes function verb F_v, function noun F_n, and function adjective F_a; FBS-based patent's behavior knowledge set β includes behaviors B_b, physical effects B_{pe}, and equation B_m; FBS-based patent's structure knowledge set γ includes structure concepts S_{sc}, features S_f, geometric features S_{gf}, and interactions S_i.

Previous studies on extracting function knowledge, behavior knowledge and structure knowledge contained in patents from patents have provided favorable support for the organization and effective utilization of knowledge. To efficiently extract knowledge from patent texts, as well as to realistically reflect the relationships between different knowledge types. The knowledge representation of the FBS-oriented design patent vocabulary used in this study is mainly in the form of using the functional verb F_v to characterize function knowledge, and using the structure concepts S_{sc} to characterize structure knowledge. Among them, the extraction of function verbs and structure concepts mainly relies on the Stanford parser.

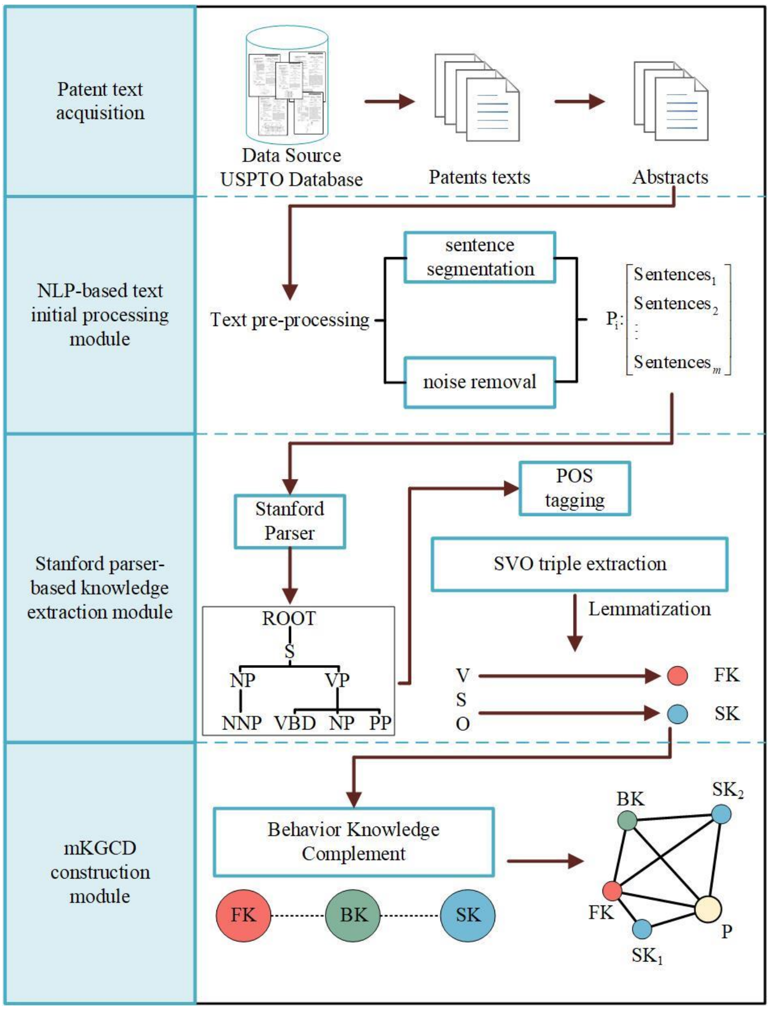

Figure 3. An improved knowledge entity recognition and relationship extraction process

The method of knowledge entity recognition and relationship extraction based on natural language processing used in this study mainly consisted of three modules: NLP-based text initial processing module, Stanford parser-based knowledge extraction module, and mKGCD construction module. The flow of the whole method is shown in Figure 3.

To build the mKGCD based on patent knowledge, the original patent text needs to be processed. First, a large number of engineering patent texts need to be collected and the corresponding abstracts of each patent need to be extracted. Secondly, the main work of the NLP-based text pre-processing module is to process the initial text of patent abstracts using NLP techniques, including sentence segmentation and noise removal. The purpose of the sentence segmentation is to separate the patent abstract T_i (i=1,2,3⋯m, $m \in N^+$) into n independent sentences A_{in}. where i represents the ith patent, and m represents the total number of patents.

$$[T_i]=\begin{bmatrix} A_{i1} & 0 & 0 & \cdots & 0 \\ 0 & A_{i2} & 0 & \cdots & 0 \\ 0 & 0 & A_{i3} & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \cdots & A_{in} \end{bmatrix} \tag{9}$$

Noise removal mainly includes punctuation removal and special character removal. Smart methods provide easy bulk removal of redundant punctuation, special characters and filtering of meaningless phrases from the text generated in pre-processing. The purpose of NLP-based text pre-processing module is to prepare for the extraction of patent-based knowledge.

After pre-processing the patent abstract text, the Stanford parser was used to perform sentence parsing and extract the knowledge about the function and structure of the patent from the abstract. Stanford Parser is a useful grammar analysis tool for part-of-speech (POS) tagging. In this study, the authors use the Stanford Parser to identify the subject-verb-object (SVO) parses of each sentence, and further filter it to obtain the different types of knowledge contained in each sentence.

$$A_{in} = S_{in} + V_{in} + O_{in} \tag{10}$$

In the identification and extraction of function and structure knowledge, the verbs V extracted by the Stanford parser were filtered, which mainly filtered verbs (such as “have” and “include”) that do not have actual function. And the filtered verb V is used to represent the function verb Fv, and the subject S and object O extracted by the Stanford analyzer are used to represent the structure concept

Ssc. Further, *Fv* was used to describe the function knowledge (FK) of the patent and use the structure concept *Ssc* to describe the structure knowledge (SK) of the patent. Then, the following mathematical expressions can be obtained:

$$\begin{cases} V_{in} \Leftrightarrow F_{vin} \Leftrightarrow FK_{in} \subset FK \\ (S_{in} + O_{in}) \Leftrightarrow S_{scin} \Leftrightarrow SK_{in} \subset SK \end{cases} \tag{11}$$

Then, each extracted word will be reduced to its basic form based on its corresponding POS tagging according to the English dictionary, which is known as Lemmatization. By parsing the abstract text of each patent P_i (i=1,2,3$\cdots m$, $m \in \mathrm{N}^+$) with the Stanford parser, the function knowledge set $FK_{i\times t}$ and the structure knowledge set $SK_{i\times t}$ corresponding to the patent P_i can be obtained. Since different patents may be divided into different numbers of *n* independent sentences, *t* in the formula represents the maximum value of n_i, where n_i denotes the number of independent sentences into which the *i*th patent abstract can be divided. In addition, the authors default to *x* representing the x^{th} row and *y* representing the y^{th} column in the matrix.

$$\begin{cases} FK_{i\times t} = \begin{bmatrix} FK_{11} & FK_{12} & FK_{13} & \cdots & FK_{1n_1} \\ FK_{21} & FK_{22} & FK_{23} & \cdots & FK_{2n_2} \\ FK_{31} & FK_{32} & FK_{33} & \cdots & FK_{3n_3} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ FK_{i1} & FK_{i2} & FK_{i3} & \cdots & FK_{in_i} \end{bmatrix}, t = \max(n_1, n_2, \cdots, \mathrm{n}_i) \\ \mathrm{FK}_{in_i} = 0, n_i < y < t \end{cases} \tag{12}$$

$$\begin{cases} SK_{i\times t} = \begin{bmatrix} SK_{11} & SK_{12} & SK_{13} & \cdots & SK_{1n_1} \\ SK_{21} & SK_{22} & SK_{23} & \cdots & SK_{2n_2} \\ SK_{31} & SK_{32} & SK_{33} & \cdots & SK_{3n_3} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ SK_{i1} & SK_{i2} & SK_{i3} & \cdots & SK_{in_i} \end{bmatrix}, t = \max(n_1, n_2, \cdots, \mathrm{n}_i) \\ \mathrm{SK}_{in_i} = 0, n_i < y < t \end{cases} \tag{13}$$

The purpose of the mKGCD graph building module is to extract the relationships between different types of knowledge based on identifying and extracting the different types of knowledge. In particular, after extracting the function knowledge FK_{in} and the structure knowledge SK_{in} from the nth sentence A_{in} in the abstract T_i of the patent P_i, the relationship between different types of knowledge can be obtained:

$$\begin{cases} R_{in}^1 = \langle P_i, have, FK_{in} \rangle \\ R_{in}^2 = \langle P_i, have, SK_{in} \rangle \\ R_{in}^3 = \langle FK_{in}, mapping, SK_{in} \rangle \end{cases} \tag{14}$$

where z in R^z denotes the number of relationships.

FBS theory explains that there is a mapping relationship between function and behavior. Stanford parser provides help to extract and construct the connection between function knowledge and behavior knowledge from patents. Stanford parser decomposes the independent sentences in patents from a grammatical perspective, abstracts the functional verb F_v and the structure concepts S_{sc} into function knowledge and structure knowledge, and further constructs the mapping relationship between function knowledge and structure knowledge from the perspective of knowledge sources.

After extracting the function knowledge and structure knowledge corresponding to each patent, and establishing the mapping relationship between patent knowledge and function knowledge and structure knowledge, as well as the mapping relationship between function knowledge and structure knowledge, the relationship between behavior knowledge and other types of knowledge needs to be established. The acquisition of behavior knowledge is most straightforward through manual complementation, but can also be achieved using some advanced artificial intelligence techniques. After completing the behavioral knowledge, a new node and three relations will be added.

$$\begin{cases} BK_{in} \in BK \\ R^4{}_{in} = \langle P_i, have, BK_{in} \rangle \\ R^5{}_{in} = \langle FK_{in}, mapping, BK_{in} \rangle \\ R^6{}_{in} = \langle SK_{in}, mapping, BK_{in} \rangle \end{cases} \tag{15}$$

After the above data acquisition and processing, finally, the mKGCD can be presented through the visualization software. Taking the Neoj4j graph database as an example, firstly, transform the nodes and relations obtained in the above operation into CSV files respectively, and then import the data through Neo4j-import, which completes the storage of this structured node and related data in the neo4j graph database. Linking all kinds of knowledge together can get a patent-based mKGCD, in which designers can retrieve the knowledge they need to get the application of that knowledge in specific patents, to get better design inspiration.

4.2 An Inventive Principle-based Label Mapping Method for Patent Classification

Conflict resolution relies on the conflict matrix, which further relies on the TRIZ inventive principles[42-43]. To avoid that patent knowledge retrieved through mKGCD does not match the inventive principle required by the designer, it is necessary to label the patent knowledge in the mKGCD, filter out the patent knowledge that can be directly used in the conflict matrix and recommend it to the designer, so as to improve the effectiveness of the recommended knowledge.

The manual classification approach to classify patents by inventive principles will consume a lot of time and effort, and on the other hand, the speed of manual classification cannot catch up with the speed of new patent generation. Therefore, an artificial intelligence model is needed to assist designers in classifying patents, and then achieve the labeling of patents in the mKGCD.

The purpose of classifying patents by inventive principle is to provide designers with a clear understanding of which class of inventive principle the specific patented knowledge retrieved through the mKGCD belongs to. The flow of the method is shown in Figure 4.

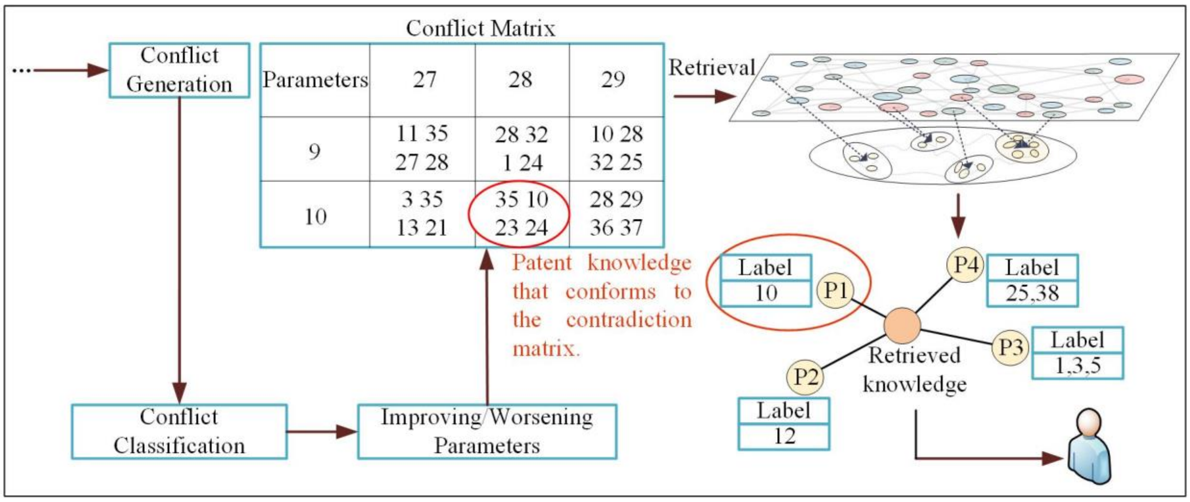

Figure 4. The process of patent labeling assisted conflict resolution

First, organizing the patent text and extracting the textual information about the description of the inventives in the patent. The description of inventives of a patent clearly expresses the innovation point of the patent. By analyzing the description of the inventive, it is possible to identify which type of inventive principle the patent innovation belongs to.

Secondly, re-classifying the inventive principle into 22 new classes. Since it is difficult to distinguish some inventive principles due to high overlap, the 40 inventive principles are re-classified into 22 classes according to textual similarity and meaning similarity to improve the classification accuracy. The results of the classification are shown in Table B in the Appendix.

Third, automatic classification was performed using SVM. F(2)-value was used to measure the performance of the SVM with the following equation:

$$\mathrm{F}(2)\text{-Value}=\frac{\left(1+2^{2}\right)Precision*Recall}{2^{2}Recall+Precision} \tag{16}$$

Finally, after classifying the patents by inventive principles, each patent has its corresponding inventive principle label. Using the visualization tool, the inventive principles label corresponding to each patent can be added to the mKGCD, so that designers can quickly understand the corresponding inventive principle when searching for a patent.

In addition, the mKGCD also has a conflict-oriented search function. Since all the patents in mKGCD are labeled with various corresponding inventive principles, designers can search not only by the required knowledge but also by the required inventive principle when conducting a search. The dual search method gives the mKGCD more powerful knowledge recommendation capability.Specifically, it mainly consists of two processes, both as shown in Equation (17) and Equation (18). the first process is to find the desired set of inventive principles *ip* by means of the conflict matrix. the second process is to find the patent set *PS* by means of *ip* and/or the desired knowledge that facilitates the design aid.

$$ip(u_0, g_0) = IP(u \to u_0, g \to g_0) \tag{17}$$

$$(P_1, P_2, P_3 \cdots P_L) = PS \subset G \tag{18}$$

Where *ip* represents the set of required inventive principles for a specific problem. *IP* represents the set of inventive principles. *u* and *g* are variables, and u_0 and g_0 are the values of a specific parameter. *L* represents the number of patents in the patent set *PS*.

4.3 A Semantic Distance-based Computational method for Implementing Knowledge Reasoning

This section will introduce how knowledge reasoning is achieved between function knowledge, and the same approach is used for behavior knowledge and structure knowledge.

To solve the conflicts arising from the conceptual design, designers need to first analyze the conflicts and find the corresponding improved parameters and worsened parameters. For example, "lightness" and "high load capacity" are a pair of conflicts. When the designer has clarified the specific parameters, he can use the mKGCD for knowledge retrieval. Designers can retrieve similar functions and their corresponding patents by retrieving function knowledge such as "lightweight" to get design inspiration.

Word2vec is an open-source tool based on deep learning, which can learn the vector representation of words in a high-dimensional vector space and can further use cosine similarity to calculate e the degree of similarity between vectors to achieve synonym clustering[44-46].

The calculation process based on semantic distance(Word2vec) is shown in Figure 5 below. First, the input is an $R \times 1$ one-hot representation of the word, and *R* is the size of the dictionary. Between the input layer and the hidden layer, there is a weight matrix $W_{R \times N}$, where *N* represents the dimension of the word vector the authors want to construct, and this weight matrix W transforms the $R \times 1$ vector into a low latitude $N \times 1$ vector. The hidden layer to the output layer also has a weight matrix W'. The final vector is further normalized using softmax to obtain the final probability distribution of the words.

The advantage of Word2vec over the traditional one-hot representation is that it can embed the high-dimensional vectors of words into a low-dimensional space, which is called Word embedding. the advantage of word2vec is that it can accomplish the task more efficiently when facing a large amount of data. The relevant formula is shown below.

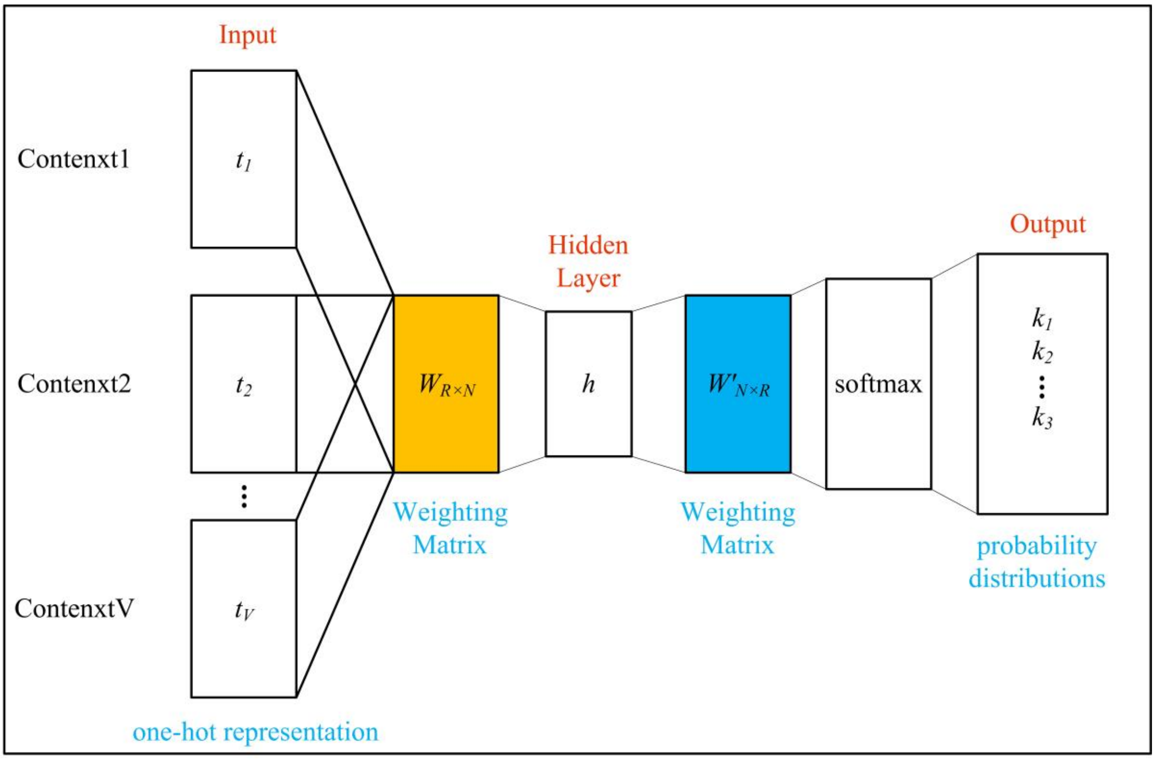

Figure 5. The calculation process based on semantic distance

$$\begin{cases} h = \frac{1}{R} W^T (t_1 + t_2 + \cdots + t_V) \\ k = softmax\left[(W')^T h \right] \\ k = [k_1, k_2 \cdots k_V]^T \end{cases} \tag{19}$$

To achieve similar knowledge reasoning and calculate the similarity between different knowledge from the perspective of text semantics, this study uses the word2vec model to encode the preprocessed text content as a vector representation in the vector space and characterize the semantic similarity of the text by calculating the similarity of two-word vectors on the vector space. This has two advantages: 1. all words of the text will be transformed into word vectors by training, and the designer can input two specific knowledge of the same type to compare their similarity. 2. the designer can input knowledge to obtain a set of knowledge with the highest semantic similarity to that knowledge in the text.

For two m-dimensional vectors $\vec{\alpha}=(\alpha_1,\alpha_2,\cdots,\alpha_m)$, $\vec{\beta}=(\beta_1,\beta_2,\cdots,\beta_m)$, the cosine similarity is calculated as follows.

$$cos\theta=\frac{\vec{\alpha}\cdot\vec{\beta}}{|\vec{\alpha}|*|\vec{\beta}|}=\frac{\alpha_1*\beta_1+\alpha_2*\beta_2+\cdots+\alpha_m*\beta_m}{\sqrt{\alpha_1^2+\alpha_2^2+\cdots+\alpha_m^2}*\sqrt{\beta_1^2+\beta_2^2+\cdots+\beta_m^2}} \quad (20)$$

This study uses use the cosine similarity calculation formula to calculate the similarity between word vectors. The calculation formula is as follows:

$$w_{i,t}=\frac{\sum_{j=1}^{m}v_{i,j}v_{t,j}}{\sqrt{\sum_{j=1}^{m}v_{i,j}^2}\times\sqrt{\sum_{j=1}^{m}v_{t,j}^2}} \quad (21)$$

where *m* denotes the dimensionality of the vector space; $w_{i,t}$ represents the similarity between the *i*th term and the *t*th term; v_{i} represents the vector representation of the *i*th term and v_{t} represents the vector representation of the *t*th term.

5. Case Study

5.1 Case Introduction

In recent years, the production scale of the manufacturing industry has gradually expanded, the degree of automation has increased significantly, installation and handling equipment in the modern production process are increasingly widely used[47]. With the continuous development of engineering technology, heavy equipment assembly, power grid system configuration and water conservancy and hydropower equipment assembly and other scenarios have put forward higher requirements for installation and handling equipment. Traditional installation and handling equipment, such as cranes, are often unable to pass through narrow transportation channels because of their large size. In the face of many complex working conditions such as small working space and heavy facilities, the existing installation and handling equipment gradually can not adapt to the needs of enterprises. Higher safety and stability at work, lighter structure and free expansion are the future trends of installation and handling equipment. To carry out the structural design of a new generation of installation and handling equipment with flexible, scalable, safe and reliable features, a knowledge system for installation and handling equipment is needed.

5.2 Construction of Knowledge Graph for Cases

The knowledge system for installation and handling equipment is a system that serves the design of installation and handling equipment products. Since the design of installation and handling equipment is an interdisciplinary and cross-disciplinary design problem, it often requires the use of knowledge from multiple fields for innovative design, so our proposed knowledge system is a design system based on knowledge graph.

In the previous period, the authors collected 2532 patents related to the field of engineering equipment from the United States Patent and Trademark Office (USPTO) under the keywords of crane, lifting equipment, lifting machinery, handling machinery, and moving device. After screening, 2341 relevant patents were finally retained. To build an installed handling equipment-based mKGCD, these patents need to be analyzed. This study chose a patent to demonstrate the steps of the analysis, which are as follows.

First, the abstract text T_1 of the patent needs to be pre-processed into seven separate sentences, and the results are shown in the table below.

Table 1 Seven separate sentences separated by the abstract text T_1 of the patent.

Name	**Method and apparatus for forming a mast assembly**
A_{11}	A method and apparatus for forming a mast assembly upon a floor of a drilling rig has a support structure.
A_{12}	A first carriage assembly affixed to one side of the support structure.
A_{13}	A second carriage assembly affixed to an opposite side of the support structure.
A_{14}	Each of the first and second carriage assemblies are connectable to a section of the mast assembly.
A_{15}	Drive cylinders are associated with the first and second carriage assemblies so as to cause the section of the mast assembly to move upwardly relative to the support structure.
A_{16}	While the section of the mast assembly is retained in an elevated position, another section of the mast assembly can be placed within the support structure and joined to the elevated mast section.
A_{17}	Additional mast sections can be connected together in a similar manner.

Secondly, the Standford parser was used to analyze the sentences to extract the subject-verb-object (SVO) and further extract the function knowledge and structure knowledge contained in the sentences. Here the author takes the third sentence A_{15} as the representative for extraction, and the other sentences are used similarly, as shown in Figure 6.

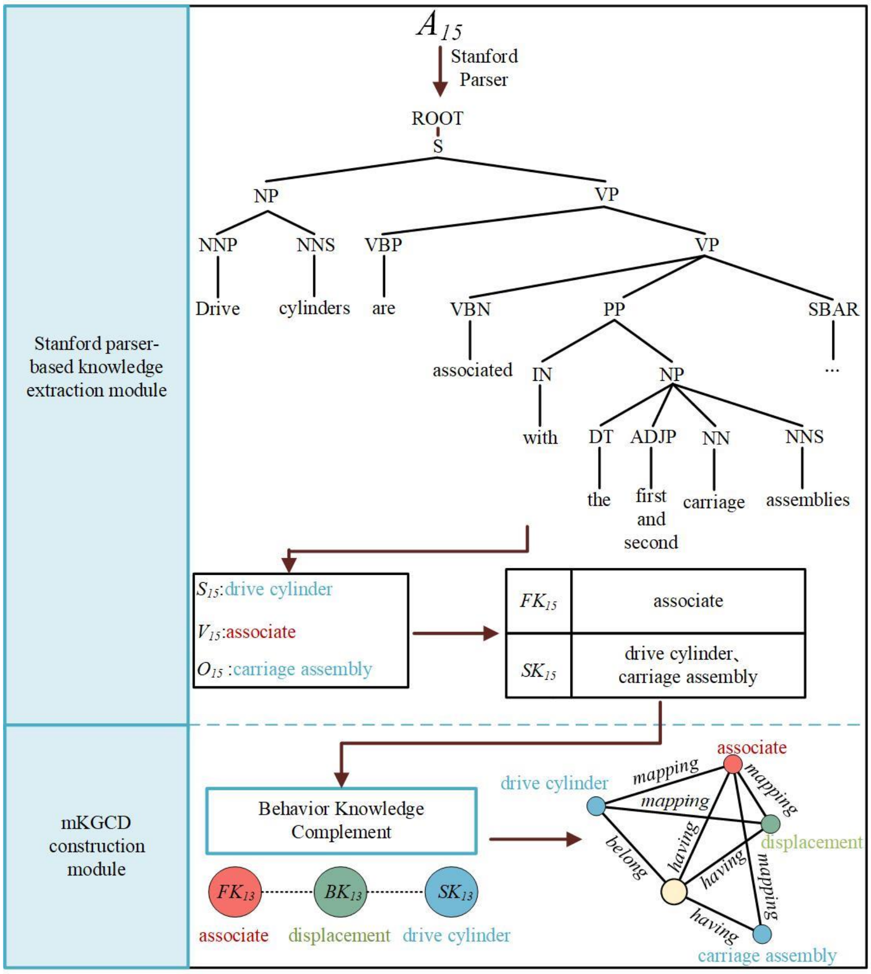

Figure 6. Knowledge extraction and organization of patented sentence

Next, each individual sentence is extracted by the same process for FK, BK, and SK, and finally obtain the $FK_{1\times 7}$ set, $BK_{1\times 7}$ set and $SK_{1\times 7}$ set of the patent.

$$FK_{1\times 7} = [\times, affix, affix, \times, associate, place、join, connect] \tag{22}$$

$$\begin{cases} SK_{1\times7} = [SK_{11}, SK_{12}, SK_{13}, SK_{14}, SK_{15}, SK_{16}, SK_{17}] \\ SK_{11} = [\times,\ support\ structure] \\ SK_{12} = [first\ carriage\ assembly, support\ structure] \\ SK_{13} = [second\ carriage\ assembly, support\ structure] \\ SK_{14} = [carriage\ assembly, mast\ assembly] \\ SK_{15} = [drive\ cylinder, carriage\ assembly] \\ SK_{16} = [mast\ assembly, support\ structure, mast\ section] \\ SK_{17} = [mast\ section] \end{cases} \tag{23}$$

$$BK_{1\times7} = [\times, stress, stress, \times, displacement, displacement, \times] \tag{24}$$

where x in the $BK_{1\times7}$ set indicates that no suitable behavior was found to fill in.

Finally, by organizing the various types of knowledge together, a mKGCD of a single patent is constructed. The same method can be used to obtain mKGCD of other patents. After the patents are classified by SVM and review, the designer can find the corresponding inventive principle labels of the patents in the graph. Figure 7 below shows the mKGCD based on two patents.

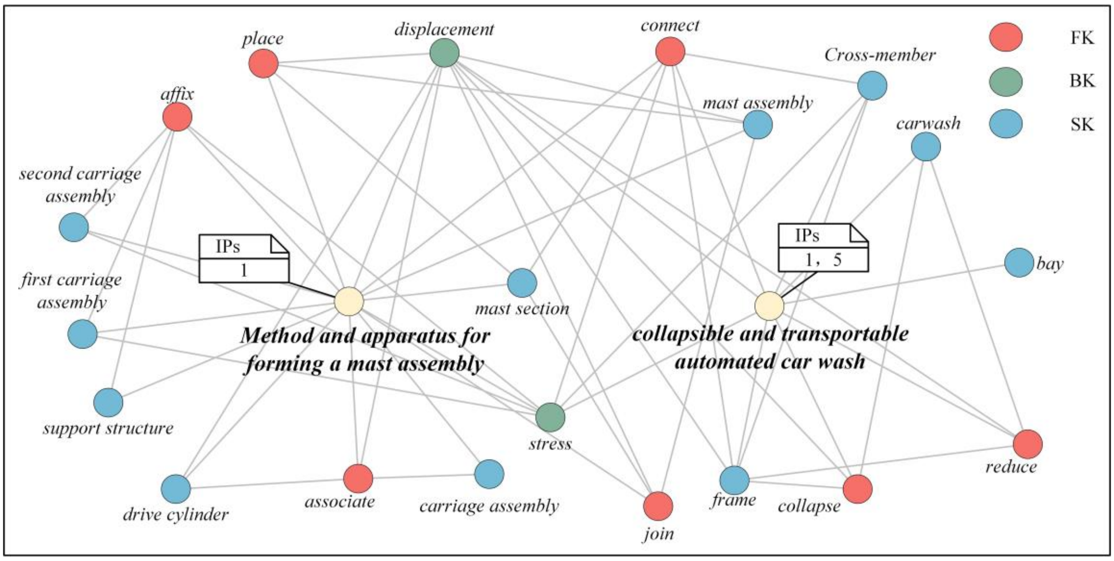

Figure 7. An example of the knowledge graph

5.3 Conflict Resolution for the Collapsible Installation and Handling Equipment

When designing a product for a new generation of installation and handling equipment, it is necessary to analyze the conflict of the product first in the conceptual design phase. The existing traditional installation and handling equipment in the narrow passage can not pass is the engineering problems faced by the designers. The designers wanted a new generation of installation and handling equipment that was lighter in weight and had the flexibility to be folded to facilitate passage through narrow passages.

The size of the narrow passage limits the overall size of the new generation of collapsible installation and handling equipment. To ensure the mobility flexibility and reliability of the equipment, the size, load capacity, and other parameters of the product need to meet the requirements as shown in Table 3.

Table 3 Parameters requirements

Maximum Size			**Minimum Size**			**Hydraulic Cylinder Working Capacity**
Length	**Width**	**Height**	**Length**	**Width**	**Height**	
2900mm	9200mm	5300mm	2900mm	1800mm	1900mm	0~300MPa
Maximum Load			**Traveling Speed**			**Lifting Speed**
10t			0~3m/min			0.8m/min

Through the analysis, it was found that the parameter of improving compared with the traditional equipment is the weight of the moving object, and the lighter weight will inevitably bring poor stability, so stability is the parameter of worsening.

For the conflict between the weight of the moving object and stability, the conflict matrix provides four inventive principles that can resolve this conflict, and the results are shown in the table below.

Table 4 Conflict matrix of the weight of moving object and stability

Worsening parameter / **Improving parameter**	**Stability**
Weight of the Moving Object	1. Segmentation 19. Periodic Action 35. Parameter Changes 39. Inert Atmosphere

The conflict matrix indicates the inventive principles required by the designer to solve the conflict, and each inventive principle can be used to solve the conflict. To show the process of applying inventive principles to conflict resolution and assisting in completing product design, some inventive principles are used for demonstration.

Understanding the inventive principle required to solve the actual engineering problem, the designer can use the mKGCD to retrieve the function knowledge and the inventive principle, and the process is shown in the following Figure 8.

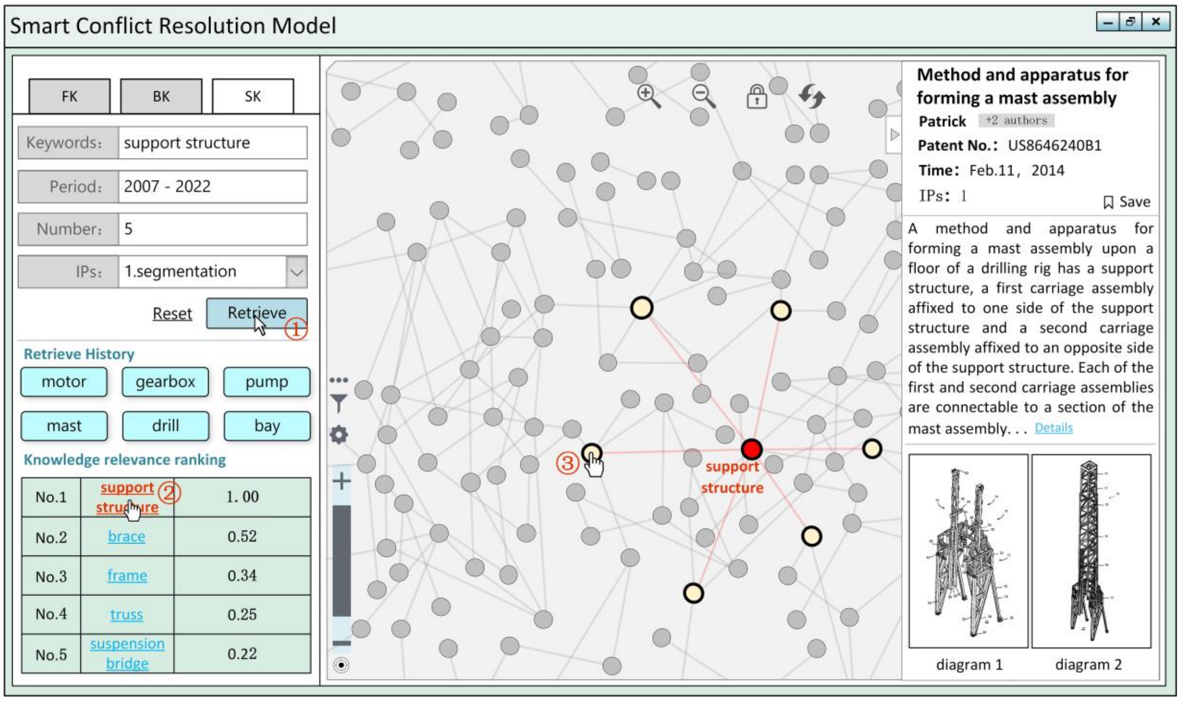

Figure 8. Interface diagram of the smart conflict resolution model

The first step is the parameter setting. After the designer selects the knowledge type and enters the keywords, the year interval of the patent expected to be found, the inventive principle expected to be obtained and the number of similar patents expected to be obtained, the knowledge retrieval can be realized by clicking retrieve.

The second step is the similar knowledge recommended by the similarity algorithm, and the designer can click on the knowledge of interest to search, to get the patents related to that knowledge.

The third step, the designer can also click the node of the patent to check the related information, including the name, author, publication time and abstract of the patent.

Through searching, a patent that matched the desired inventive principle was found that describes a way to assemble a mast assembly on a drilling rig. The purpose of the patent is to solve the problem of difficult disassembly and high transportation costs of oil drilling equipment in large drilling operations. The modular mast sections are connected together, in the same way, to facilitate disassembly and ensure stability during work. Based on this case study, a single-stage hydraulic lifting structure was designed for collapsible installation and handling equipment. The designed single-stage hydraulic lifting mechanism is shown in Figure 9.

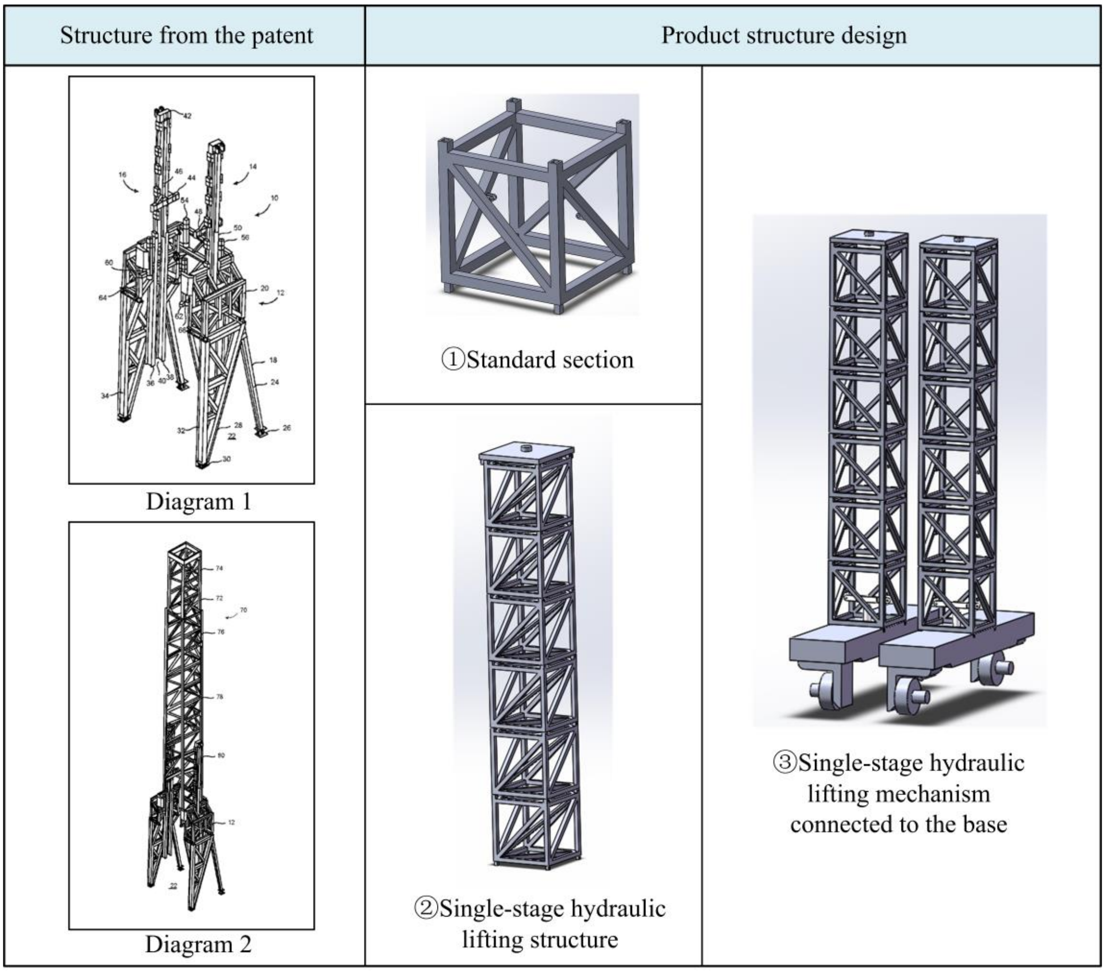

Figure 9. Single-stage hydraulic lifting structure design

Similarly, the same steps can be used to design other structures for collapsible installation and handling equipment such as crossbeams.

5.4 Design of a Collapsible Installation and Handling Equipment

Other structures of the collapsible installation and handling equipment, such as wheels, covers, crossbeams, etc., were designed by the smart conflict resolution model. The final design of the overall mechanical structure of the collapsible installation and handling equipment is shown in Figure 10, which shows the overall mechanical structure of the designed collapsible installation and handling equipment and the movement process of the product.

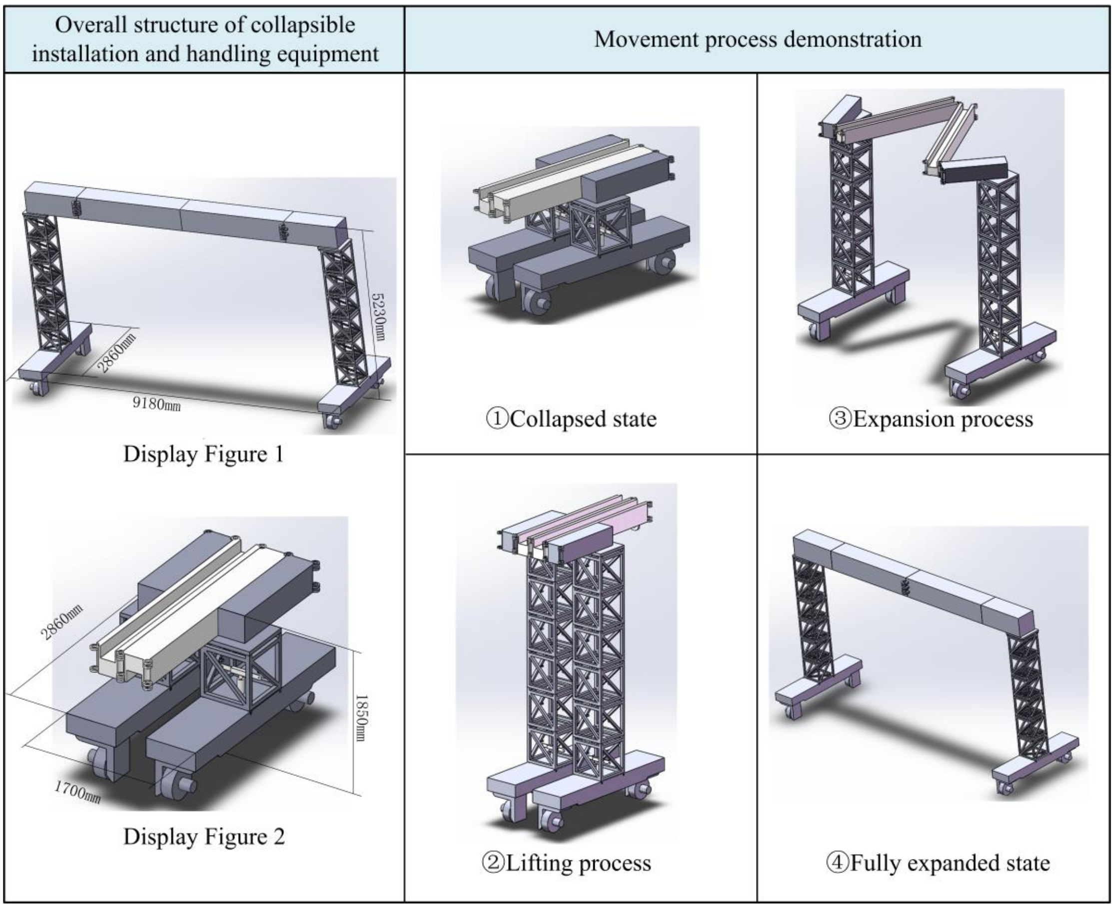

Figure 10. The overall mechanical structure and movement demonstration

The mechanical structure of a collapsible installation and handling equipment has been innovatively designed using the smart conflict resolution model. In order to make the collapsible installation and handling equipment smarter and more convenient during the telescoping process, the same conflict resolution steps were used to upgrade the product, as shown in Figure 11. The energized coils ensure smooth rotation of the crossbeam during telescoping through electromagnetic force, and the angle sensors provide real-time monitoring. The energized coils and angle sensors jointly ensure the coordination of the collapsible installation and handling equipment during symmetrical telescoping and improve the automation and intelligence of the collapsible installation and handling equipment.

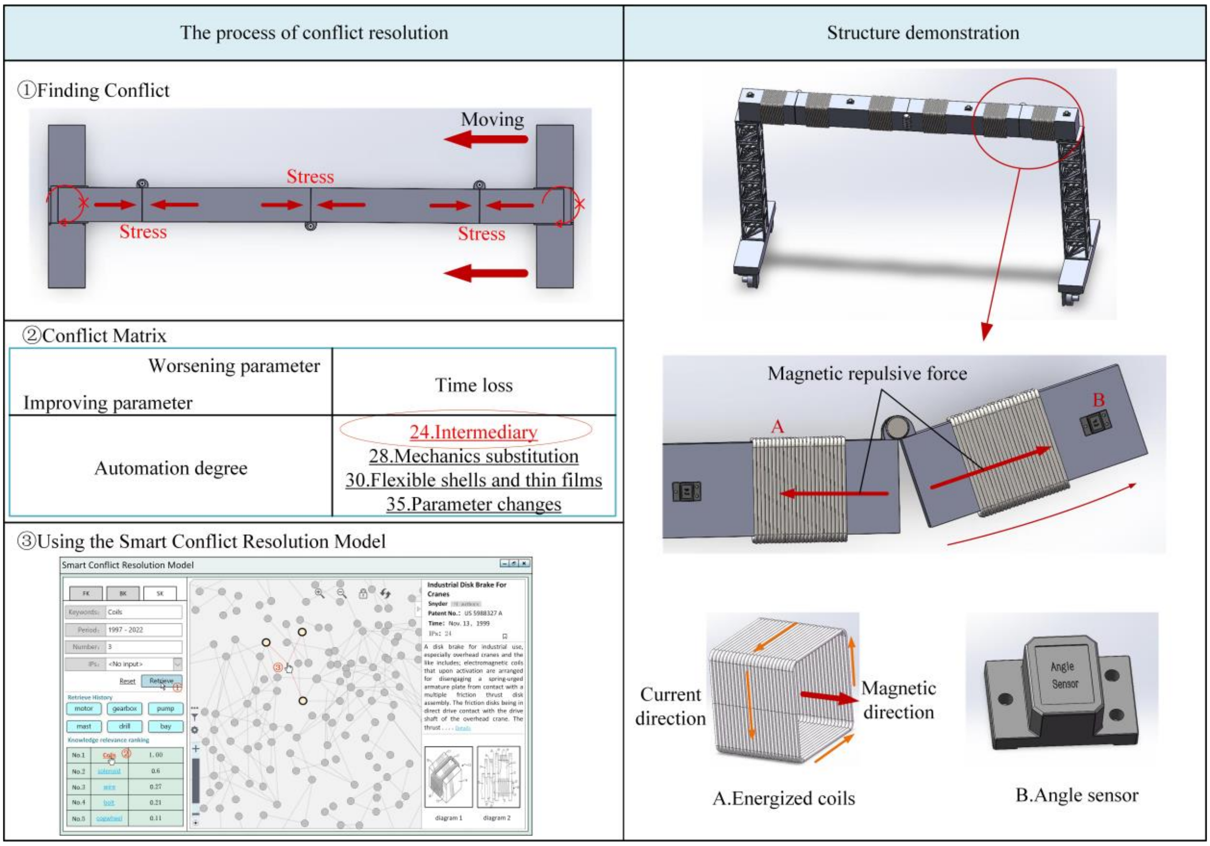

Figure 11. Conflict resolution to guarantee coordination during telescoping process.

Compared with previous installation and handling equipment, this product achieves lightweight while maintaining structural stability. When encountering narrow passages, they can be flexibly collapsed to pass through them. The collapsible installation and handling equipment not only enables quick assembly and saves a lot of transportation costs, but also expands the use scenes.

6. Discussion

Conceptual design is an important part of innovation design. Previously, many research scholars have proposed many effective methods, models, and strategies for conflict resolution in conceptual design. The strength of this study is the use of knowledge graph to model conflict resolution in the design process. The proposed smart conflict resolution model using the mKGCD includes a detailed set of conflict resolution processes, two smart methods to construct mKGCD and a knowledge reasoning method based on semantic distance calculation in order to facilitate the relationship between the conceptual design process, conflict resolution methods and knowledge reasoning systems.

By extracting and organizing the important design knowledge hidden in patents, the smart conflict resolution model can assist designers to search for relevant cases for real engineering problems. In particular, unlike the various semantic networks proposed in the past, the knowledge recommended by mKGCD is the specific patents that conform to the inventive principles , and these patents reflect the specific application of the abstract knowledge required by designers, which can better stimulate designers' innovation.

The mKGCD integrates a variety of design knowledge of patents, including function knowledge, behavior knowledge, structure knowledge and patent knowledge. The hierarchical knowledge organization system realizes multiple meanings in one graph, which can assist designers to retrieve various types of knowledge that are conducive to inspiring design according to their needs. In the future, the mKGCD can continuously expand the knowledge layers according to the design requirements, for example, by collecting and analyzing users' requirements and adding requirement layers to the existing foundation. The core idea of mKGCD is to cover a variety of design knowledge required in the design process through one knowledge graph, to solve various problems encountered in the design process for designers.

A knowledge organization system that conforms to the basic process and mapping rules of conceptual design is constructed, which is beneficial to push appropriate knowledge at different conflict resolution stages in the design process. Such knowledge deployment is commonly required in function, behavior, or structure mapping and its conflict resolution. This knowledge deployment enables the resolution of conflicts corresponding to different levels of conceptual design, which reflects the proposed model's focus on the continuity of conflicts. In addition, as conceptual design proceeds, the design conflicts vary at different stages. A hierarchical knowledge organization approach networks a large number of cross-domain and multidisciplinary patent resources, and different types of conflicts can find the corresponding referred cases in the knowledge resources, which reflects the model's concern for the diversity of conflicts.

However, it should be acknowledged that the mKGCD -based smart conflict resolution model is still a conceptual model, which is based on our understanding of conceptual design and conflict resolution. The proposed model still has limitations: 1) Multi-source heterogeneous knowledge can assist innovation more comprehensively. In the future, the authors hope that a more intelligent knowledge extraction model can achieve not only high-precision automatic knowledge extraction of patent texts, but also achieve knowledge extraction of multi-source data, which can certainly greatly improve the efficiency of building large mKGCD. 2) Knowledge is hidden[48-49]. The construction of knowledge graph using cross-domain knowledge requires the analysis of the logical relationships implicit in the knowledge. This is full of the empirical organization process. How to achieve self-organization and self-reasoning under the construct of mKGCD is still one of the limitations of the model. 3) The smart conflict resolution model can be combined with a smarter approach for conceptual solution evaluation and decision-making, which facilitates quantifying the gap between design solutions and user requirements and enables better correction of deviations in conceptual design direction. This is an important means of quantifying the efficiency and effectiveness of knowledge-assisted conceptual design.

Since conceptual design is a decision-making process where empirical, uncertainty and complexity coexist, the knowledge required and the conflicts faced by different product design tasks vary greatly. In the future, mKGCD can be applied to different conceptual design tasks with the support of a group of designers with different professional experience to further revise and improve the model by means of comparative studies. It will also be used as a guideline for further development of the study.

7. Conclusion

The process of product innovation is also the process of product conflict resolution. In this study, a smart conflict resolution model using mKGCD to resolve conflicts is proposed. From the perspective of conflict resolution, our contribution is twofold. First, a four-layer semantic network for conflict resolution is constructed by natural language processing techniques and an inventive principle-based label mapping method to organize patent-related design knowledge to cope with the diversity of conflicts. Secondly, through the innovation of the conceptual design stage process, mKGCD is applied to the FBS multi-layer mapping process to cope with the continuity of conflicts, which facilitates the timely detection and resolution of conflicts in the design process. Through the calculation of semantic distance, the designer can obtain appropriate knowledge that conforms to the inventive principle by retrieving the mKGCD in each part of the design process, which improves the efficiency and reliability of the design. To verify its feasibility, this study presents a case study of a collapsible installation and handling equipment that can flexibly navigate through narrow passages. The results show that the proposed model can effectively help designers in innovative product design.

Acknowledgment

This research was partially supported by three projects from the Sichuan Science and Technology Program (22ZDZX0003, 2022YFG0065, and 2021ZDZX0005).

Appendix A. 40 inventive principles

Principle 1	**Principle 2**	**Principle 3**	**Principle 4**	**Principle 5**
Segmentation	Extraction	Local Quality	Asymmetry	Merging
Principle 6	**Principle 7**	**Principle 8**	**Principle 9**	**Principle 10**
Universality	Nested Doll	Anti-weight	Preliminary anti-action	Preliminary action
Principle 11	**Principle 12**	**Principle 13**	**Principle 14**	**Principle 15**
Beforehand Cushioning	Equipotentiality	Inversion	Spheroidality Curvature	Dynamics
Principle 16	**Principle 17**	**Principle 18**	**Principle 19**	**Principle 20**
Partial or excessive actions	Another Dimension	Mechanical vibration	Periodic action	Continuity of useful action
Principle 21	**Principle 22**	**Principle 23**	**Principle 24**	**Principle 25**
Skipping	convert harm into benefit	Feedback	Intermediary	Self-service
Principle 26	**Principle 27**	**Principle 28**	**Principle 29**	**Principle 30**
Copying	Cheap short-living objects	Mechanics substitution	Pneumatics and hydraulics	Flexible shells and thin films
Principle 31	**Principle 32**	**Principle 33**	**Principle 34**	**Principle 35**
Porous materials	Color changes	Homogeneity	Discarding and recovering	Parameter changes
Principle 36	**Principle 37**	**Principle 38**	**Principle 39**	**Principle 40**
Phase transitions	Thermal expansion	Strong oxidants	Inert atmosphere	Composite materials

Appendix B. 22 new categories of inventive principles

Categories	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Principles	1,5,6,15	2,3,33	4	7,31	8,29,39	9,10,11	12,13	14	16,21	17	18
Categories	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Principles	19	20	22,25	23	24	26,28,32	27,34	30	35,36,37	38	40

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