BIM Model Components Retrieval Method Based on Visual Attention

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Abstract. Retrieval is an important way to achieve the interactive visualization of multidimensional dynamic building big data. However, the traditional keyword-based retrieval method lacks the ability to retrieve and rank the BIM model components. In this paper, a new method is proposed for BIM model components retrieval and ranking based on user's visual attention. Firstly, a visual attention point is picked up by analyzing the interaction principle of users. Then the spatial coordinates of components are extracted on the basis of the IFC definition method. Finally, according to the defined building model indoor road network, the reachable distances between each components and the user's visual attention point are obtained, and then the optimal components retrieval result is determined by the distances. The experimental result shows that this method not only allows users to quickly, timely, and fully access the required component information, but also satisfies the application of the building model at various stages.

Keywords: BIM, IFC, reachable distance, retrieval, visual attention

1 Introduction

Building information modeling (BIM) is a process involving the generation and management of digital representations of physical and functional characteristics of places [1]. BIM enables cross-organizational, cross-phase, cross-application building data to be used interoperable, and plays an important role in improving production efficiency, savings cost and reducing construction time. With the growing maturity, multidisciplinary information parameters are gradually integrated, which leads to an increase in volume of BIM model. In the entire life cycle of the building, BIM models are applied to different users, devices and situations from design to operation and maintenance. Therefore, the information interaction method that satisfies the user's needs should be adopted as soon as possible.

Now information retrieval has become an important means of information acquisition in BIM model. But there are many deficiencies when traditional keyword-based retrieval method applied to BIM model. As shown in Fig. 1, there are the components retrieval results of a BIM model based on keyword retrieval method. Even though 289 results of related "door" components have been generated, the retrieval results are random. Users can't efficiently and accurately find specific components of requirement, but still need to manually select them. This increases the time and difficulty of obtaining information. For this kind of situation, appropriate retrieval algorithm should be adopted after fully considering the information needs of users in the BIM field.

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Fig. 1. Keyword-based retrieval results

In the field of BIM, some scholars have done research on retrieval. Lin and others [2-3] use natural semantic and its semantic extension method for the retrieval of BIM model product library. This method is aimed at online BIM product library, and is not suitable for the BIM model components retrieval. Daum and others [4-5] analysis the application of topological relations in BIM retrieval, which is mainly applied to the retrieval of sub models. Mazairac and others [6] focus on the development of query language framework in the field of architecture, which lacks of research on the BIM model itself. Although the above retrieval methods are innovative, there is a lack of interactive BIM model components retrieval method.

Therefore, this paper put forward a new solution based on user's visual attention and reachable distance. Inspired by general recommendation algorithm, by using WEBGL technology and IFC standard, by considering user interaction method and the characteristics of BIM model, we propose a new BIM model components retrieval and ranking method. And we integrate our method into a self-developed Web-based BIM model presentation platform. Then the validity of the method is demonstrated by experiments. The details are as follows.

2 Related Work

2.1 General Recommendation Algorithm

Retrieval algorithm has always been a hot issue in information processing, such as the content-based recommend-dation algorithm [7], algorithm based on collaborative filtering [8] and hybrid recommendation algorithm [9-10]. Some scholars use machine learning methods to solve ranking problems [11-12], or use semantic similarity measure [13-14]. In addition, there are methods based on the support vector machine [15] or the ranking model RankNet [16]. The above retrieval recommendation algorithms are innovative and groundbreaking to some extent. But because of multi-dimensional dynamic characteristics of BIM, they are not suitable for BIM model directly. But we can make use of the recommended ideas to propose a new retrieval method suitable for BIM model.

2.2 BIM Model Display Based on WEBGL

During the gradual popularization, BIM models have been applied to different platforms and exhibited in different ways. In order to meet the cross platform display requirements and solve the problem of interoperability between different scenarios, different hardware devices and different operating systems, BIM model display technology based on WEBGL [17] has gradually become a hot issue of study.

WEBGL is a technology that supports rendering, displaying and interacting 3D model in a browser. The program of this technology runs in the browser, where there is no need to install any special plug-in or library files, only need to write the functions to be implemented into JavaScript programs to the browser [18]. It has many operations such as model loading, illumination, coloring and so on. Among them, scene roaming and zooming are the most intuitive operations for users, which can be served as the basis for interactive retrieval.

2.3 Industry Foundation Classes

In the practical application of construction projects, BIM data has the characteristics of multi-source and heterogeneous, which brings technical challenges of information transfer in the whole life cycle. In order to improve the applicability of BIM model retrieval method, IFC data format is adopted in this paper. Industry Foundation Classes (IFC) standard [19] is a general standard issued by buildingSMART, which aims to achieve information sharing and exchange of BIM. Because of the unique advantages in object definition and data sharing, it has received wide recognition in the field of AEC. Because of the rich information contained in the IFC standard, it is chosen as the basis of this interactive retrieval method. Our method makes full use of attribute definition method, relation information definition rule, geometric expression type, space definition rule in IFC. The specific extraction method and application analysis are given in the following sections.

3 BIM Model Components Retrieval Method

Considering the interaction principle of users on web and definition rules of components in IFC standard, we rank retrieval results based on the reachable spatial distances between components and the user. That is, the closer the spatial distance is, the higher the weight of the component. As shown in Fig. 2, we first retrieve all components to be sorted by keyword-based method, then determine the user's visual attention point which represents the location of user in three-dimensional architectural space by analyzing the user interaction method and WebGL 3D display principle [18]. Next, select the appropriate extraction method to point parameterize all the components in order to get their spatial coordinates. Finally, by defining the reachable indoor road network, obtain the reachable distances of the components to be sorted from the user's visual attention point, calculate the results and rank them accordingly. The proposed method is applied to the BIM model platform to demonstrate the practicality and efficiency.
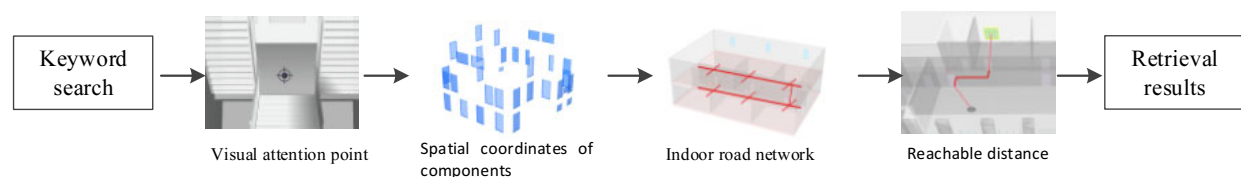

Fig. 2. Flow chart of retrieval method

3.1 Keyword Search

In order to rank, an appropriate method needs to be adopted to extract all relevant components. For BIM, more than 600 building entities are defined in IFC, and all attributes associated with entity objects can be abstracted by their own attribute mechanism. The IFC document of BIM model has a wealth of property information that is property resources (IfcPropertyResourse). The lfcProperty defines an abstract concept of all attribute types and it is associated with IFC objects through the attribute set mechanism. Due to the rich semantic description features (such as Name, Description) in IFC, the keyword retrieval method can be directly used to query the compo-nents which need to be ranked.

According to the above characteristics of BIM model and IFC standard, we search keyword directly. During retrieval, user browses the BIM model to a certain interface, inputs the keyword of the required component, we define it as query q. For query q, perform full-text string matching on this IFC document of the BIM model and mark all components that match this string. After that, all the relevant components matching the keyword have been obtained, we define them as the component set Cn. And each component in the IFC document has its own specific GUID, which can be used for ranking recognition in the next stage.

3.2 User's Visual Attention Point Select

In the face of a complex scene, human attention is quickly concentrated on a few prominent visual objects, and those objects are prioritized. The above situation is called visual attention, and the most prominent visual object is called the focus of attention [20]. There is only one focus of attention at the

same time. For BIM, the user first pays attention to the center of the screen, that is, the focus of attention, which can represent the position of the user in the 3D model space. User's information behavior is driven by information needs, so the spatial distance calculation based on the user's visual attention point could be the most suitable way.

When user browses the BIM model on Web, WebGL displays the model in visual space. The projection transfor-mation rule defines the rendering degree of the visual space and how it is mapped to the computer screen. As shown in Fig. 3, the perspective projection matrix determines the perspective projection visual space by defining the verti-cal view angle (fov), the aspect ratio of the near clipping surface (aspect), and the position of the near and far clipping surfaces (near, far). The different forms of the model are displayed by transforming the matrix of X, Y, Z in different directions and changing the perspective projection matrix.
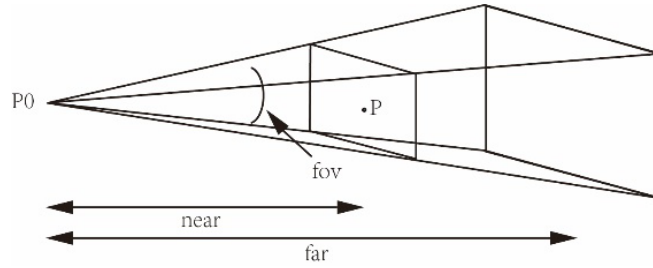

Fig. 3. Principle of user's visual attention point on Web

Considering the imaging characteristics of the 3D model on Web, the world coordinate of the origin in the visible space under the initial state can be obtained according to the rendering rules of the model visual space, we define it as $P_0(x_0, y_0, z_0)$. In the process of browsing model, the real time origin coordinate $P_w(x_w, y_w, z_w)$ can be obtained by calculating the rotation and translation of $P_0(x_0, y_0, z_0)$. In this paper, the center point of the near clipping surface (P in Fig. 3) is selected as the visual attention focus point. The world coordinate of the dynamic $P(x, y, z)$ can be obtained from $P_w(x_w, y_w, z_w)$ by matrix transformation of imaging direction and the near value. $P(x, y, z)$ is the focus point of visual attention which can be served as a reference point for calculating spatial distance in the next stage.

3.3 Spatial Coordinates of Components Extract

Component's center point extract. After obtaining all Cn, we need to extract its location in the model space. Because the method of spatial distance calculation is adopted, it is necessary to simplify the component into a single point coo-rdinate. There are a variety of geometry representations in IFC, and the following three are commonly used. One is SwepSolid, which describes the three-dimensional coordinates of the two-dimensional cross-section (By Extruded-AreaSolid) and stretches or rotates to get solid along the direction (ExtrudedDirection) and length (ExtrudedLength) values. The second one is Brep, which describes different shells and faces to build geometry of entity. The shells and faces are described by vertex coordinates (IFCCartesian). The third one is CSG, which describes complex entity that can be obtained from basic geometric entities by Boolean operations. So for different geometry representation types of components, a suitable approximate center geometric point extraction method should be adopted.

For convenience, we transform all components which use different expression methods into the Brep (Type in Fig. 4) through three processes: standard vertex computation, boundary reorganization and topological reconstru-ction. After processing the geometric component, select all vertex coordinates (IFCCartesian), and obtain the mini-mum coordinate $S_{min}(X_{min}, Y_{min}, Z_{min})$ and the maximum coordinate of the component. Calculate:

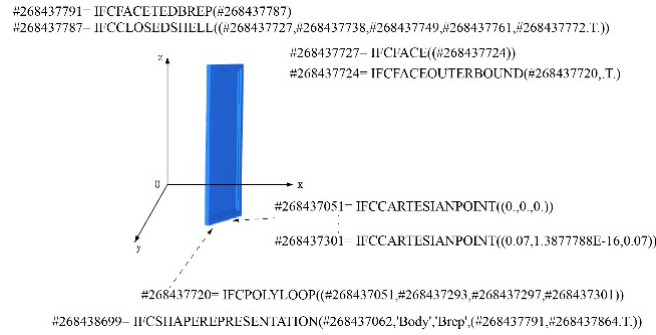$$S = \left(\frac{X_{max} + X_{min}}{2}, \frac{Y_{max} + Y_{min}}{2}, \frac{Z_{max} + Z_{min}}{2} \right). \tag{1}$$

#268437791– IFCFACETEDBREP(#268437787)
#268437787– IFCCLOSEDSHELL((#268437727,#268437738,#268437749,#268437761,#268437772.T.))

#268437727– IFCFACE((#268437724))
#268437724= IFCFACEOUTERBOUND(#268437720,.T.)

#268437051– IFCCARTESIANPOINT((0.,0.,0.))
#268437301– IFCCARTESIANPOINT((0.07,1.3877788E-16,0.07))

#268437720= IFCPOLYLOOP((#268437051,#268437293,#268437297,#268437301))
#268438699– IFCSHAPEREPRESENTATION(#268437062,'Body','Brep',(#268437791,#268437864.T.))

Fig. 4. The Brep geometry representation type

S can be used as the approximate geometric center point of the component entity. After calculation, all components Cn have their corresponding coordinate points which are noted as $S_l (x, y, z)$.

Coordinates transform. The coordinates $S_l (x, y, z)$ obtained in the previous stage are local coordinate points, which can't meet the requirements of spatial calculation, so we need to identify the world coordinates of the components. In IFC, the component is drawn in the section coordinate system, the section coordinate system is rotated and translated by local coordinate system, and the local coordinate system is rotated and translated from the world coordinate system. As shown in Fig. 5, the world coordinate system in IFC is nested by multi-layer coordinate system. And the local coordinate system is obtained by defining the origin (IfcCartesianPoin), Z axis and X axis (IfcDirection).
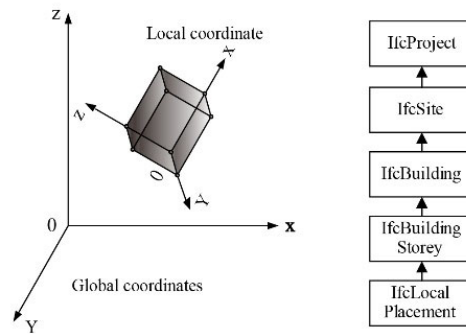

Fig. 5. Coordinate system transformation

So we have to solve the problem of rotation and translation between the world coordinate system and the local coordinate system. As shown in Fig. 5, the directional cosine of the relative coordinate system and the coordinate axis should be established first, then the coordinates of the components in the world coordinate system should be obtained by rotating the translation matrix layer by layer. The local coordinates of components is extracted by the previous method, so next we need to reverse the rotation matrix to get the world coordinates of the components. Specifically, the component calculation point S_l is transformed from the local coordinate system L to the world coordinate system G. The following equation transforms the local coordinate S_l to the world coordinate S_g:

$$S_g = S_l M_{l-g} . \qquad (2)$$

The transformation matrix M_{l-g} is:

$$M_{l-g} = \begin{bmatrix} icx & icy & icz & 0 \\ jcx & jcy & jcz & 0 \\ kcx & kcy & kcy & 0 \\ tcx & tcy & tcz & 1 \end{bmatrix} . \qquad (3)$$

The ic, jc, kc are the unit basis vectors of the x, y, z axis in the sub coordinate system, and these vectors can be represented by the paternal spatial coordinates. tc is the translation of the sub coordinate

system relative to the global coordinate system. By extracting the corresponding data from the component IFC file, it is easy to obtain the world coordinates $S_g(x, y, z)$ after transformation. After that the components in the corresponding component set Cn have their corresponding spatial coordinates S_g.

3.4 Road Network Construct and Reachable Distance Calculate

The reference point and the data to be calculated have been extracted, which are the visual attention point P and components spatial coordinates S_g. The traditional method of distance sorting is to calculate the straight distance, which means the closer the distance is, the higher the weight of component. But for BIM model, due to the functional characteristics and space constraints of the building, the component with the shortest distance may not be the most matched one. For example, because of the limitation of wall and other factors, component A has shorter straight distance and higher weight than component B which is in the same room with the user. But theoretically component B is more suitable for the user's needs. Therefore, to avoid such a problem, the concept of reachable distance is proposed and used as a ranking criterion.

Due to the limit of space such as rooms, people have to go through a certain path in the building space to get to the place they want to go [21]. Therefore, we simulate the actual situation of users in the building space, define the path that user needs to go through to get the components, and take the reachable distance as the ranking criterion. Specifically, the components to be ranked are limited to their respective rooms, and then connected to the defined indoor public road network through the door node. At the same time, the visual attention point is connected to the public network through the door node. A complete pathway can be formed in this way. We define the distance that the component reaches the visual attention point through the network as the reachable distance.

The road network required for our method is an indoor public road network. In IFC standard, not only entity components such as IfcDoor and IfcStair are defined, but also the internal structure of each floor is described by IfcSpace type, which is divided into rooms, corridors and offices according to different characteristics. So we extract the LongName attribute values of IfcSpace in IFC to get corridor, room, office and so on as the elements of road network construction. In this paper, we construct the network by picking up the central axis. As shown in Fig. 6, the node a is formed by connecting bisector $r1$ and bisector $r2$. The axis line ab is formed by connecting node a and node b, that is, the central axis of this corridor space. As shown in Fig. 7, the axis of the stair cd is formed in the same way. At last, select the midpoints of the doors in the floor plane and connect the points with the road network vertically. Fig. 8 is a schematic diagram for the indoor road network of a floor.

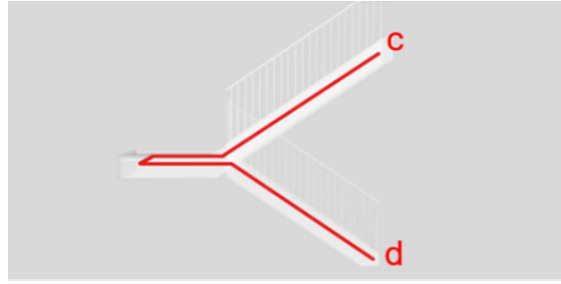**Fig. 6.** Determination method of indoor road network

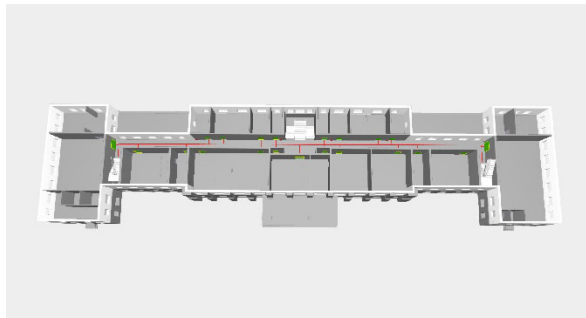**Fig. 7.** Central axis of a stair

Fig. 8. Indoor road network of one floor

During retrieval, point $S_g(x, y, z)$ is connected with the user's visual attention point $P(x, y, z)$ through defined road network. But there are different paths, so Dijkstra algorithm is used to select the shortest reachable distance between a single component and the user's visual point, and the reachable distance value Dn of all components can be obtained. According to the result of distance calculation, we need to rank it to determine the optimal components. The radix sorting algorithm is adopted in our method, and the algorithm complexity is O (n). And then the ranking display of components retrieval results can be obtained by using the corresponding components' GUID.

4 Experiment

4.1 Application

The presented method has been integrated into a self-developed Web-based BIM model presentation platform [22] to demonstrate the practicability and efficiency. The platform is based on B/S (Browser/ Server) network application framework. And the NoSQL database based on distributed file storage is used to store data. For interface design, we adopt HTML5 standard to achieve model retrieval operation on web. Specifically, user interface is shown in Fig. 9. When browsing the model to a certain perspective, user can input the name of required component in the retrieval toolbar. And components retrieval results would be displayed on the right side. Also by clicking the components on the toolbar, user can lock their location in 3D model.
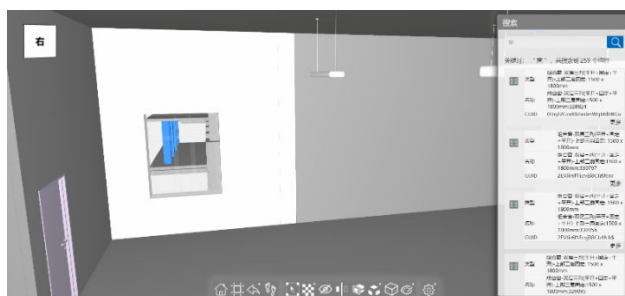

Fig. 9. Interface of retrieval

4.2   Experiment Analysis

To verify the efficiency of this method, we chose 40 BIM models from the BluePrint Product of BIM Winner Co. Ltd [23]. The 40 BIM models were sourced from different disciplines and different projects such as residential building, hospital, library and factory, etc. At the same time, to verify the applicability of this method, two platform is adopted, that is, PC and iPad. For PC, the experiments were run on a 3.60GHz processor with 16GB memory on Windows 10. And for iPad, experiments were run on an iPad Pro with 4GB memory.

This method is an interactive retrieval method, traditional evaluation index such as P@10 and recall can't directly reflect the effectiveness of it. Therefore, in order to verify the performance of the method, we select artificial experiment. For 40 sets of different BIM models, keyword-based retrieval method and our method were conducted respectively 10 times with the same initial state. In this experiment, we first define the user expected component as c, the criteria of retrieval efficiency as p. p is the probability of the user expected component c located in the retrieval Top10 results in 10 times operation. At the same time, component c is sourced from 5 types of components to verify the applicability.

The results are shown in Fig. 10(a) is the result of the PC terminal and Fig. 10(b) is the result of the iPad terminal. As shown, in many experiments of multiple models, for traditional keyword retrieval method, the proportion of user expected component to be located in Top10 is average 18% on PC and average 12.75% on iPad. The results were generally low, which leads to the fact that users still need to manually select their required components. For our method, the proportion of user expected component to be located in Top10 is average 64.5% on PC and average 59.75% on iPad which is relatively high and stable. In contrast, our method has greatly increased the proportion of component to be located in Top10 which means it satisfies users' needs as far as possible. And the retrieval results for different components are recorded in Table 1 on PC. From the Table 1, we can see that our method can improve the retrieval efficiency of various components. For example, the proportion of the component "Window" to be located in Top10 component increases from 0.0875 to 0.6625 which increase a lot. It can be seen that the retrieval efficiency has been greatly improved regardless of the type of component which proves the general applicability and stability of our method. Therefore, from the analysis, our method makes the retrieval results orderly, meets the user's needs greatly, and improves the retrieval efficiency.
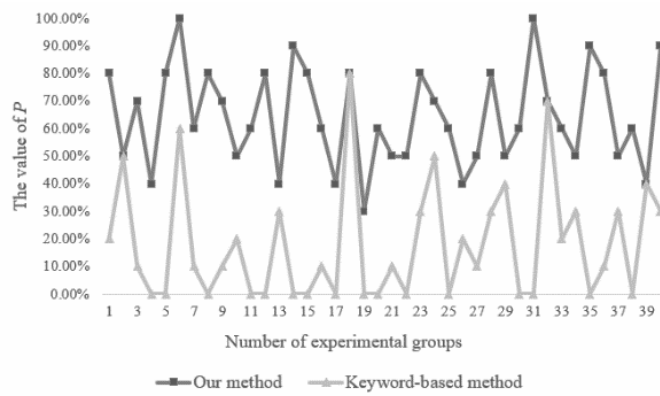
(a) Retrieval results on PC
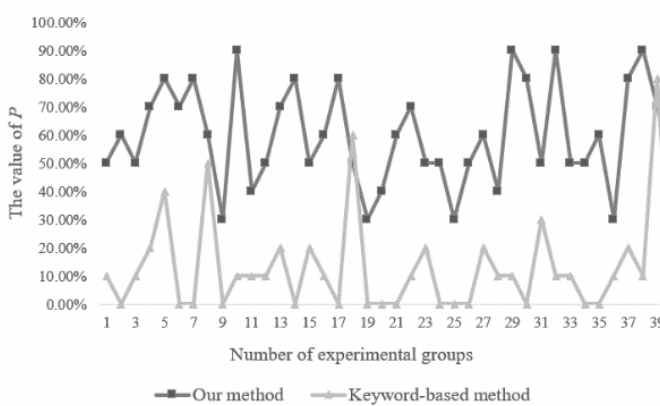
(b) Retrieval results on iPad

Fig. 10 Comparison of retrieval methods

Table 1. Retrieval results for different components on PC

	Keyword-based method	Our method
Beam	0.1875	0.7
Window	0.0875	0.6625
Door	0.2125	0.575
Lamp	0.2125	0.6375
Column	0.2	0.65

5　Conclusion and Discussion

Since the traditional keyword-based retrieval method lacks the ability to retrieve and rank the BIM model components and there are no existing solutions, after analyzing the interaction principle of user and the features of BIM model, this paper has proposed a retrieval ranking method of BIM model components based on visual attention point and reachable distance. It is a brand new interactive retrieval method and it solves the problem that users still need to select information manually in the process of retrieval. According to this method, BIM model retrieval function has been applied into a self-developed Web-based BIM model presentation platform. And based on the platform, we carry out extensive experiments. The experimental result shows that no matter what the device terminal it is, our method has improved the proportion of user expected component to be located in Top10 (from an average of 15.375% to an average of 62.125%). And it shows that this method not only allows users to quickly, timely, and fully access the required component information, but also satisfies the application of the building model at various stages.

　This method can be further optimized. For our method, in the query processing stage, the traditional keyword-based retrieval method is adopted in this paper. There is still room for improvement. For example, using semantic retrieval method and ontology to expand query can enrich the preliminary retrieval results. Further enhance the retrieval efficiency, which is our future work.

Acknowledgments

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