CAD Modeling Technology for Building Engineering Based on Extended Diagram and Polymorphic Model

Qiang Xie

School of Engineering Management and Real Estate, Henan University of Economics and Law,
Zhengzhou 450046, China, xieyuxin1979@163.com

Corresponding author: Qiang Xie, xieyuxin1979@163.com

Abstract. This paper analyzes and researches the CAD modeling technology of construction engineering through extended diagrams as well as polymorphic models. This paper takes the CAD model of the process plant as the main research object and researches the retrieval and intelligent design technology of the 3D engineering model by combining it with the actual engineering application requirements. The paper firstly proposed the unified representation method and similarity evaluation principle of engineering CAD model; then studied the global and local similarity measurement algorithm of 3D model of process plant, and the similarity measurement algorithm of 2D engineering drawing and 3D model respectively; finally realized the intelligent prediction in process plant design by mining the implicit design rules in the model. The complexity of process plant CAD models is manifested in the huge number of components and complex topological relationships. Because different process plant models have different types and numbers of topological relationships, this paper firstly proposes a relationship tree model to count the distribution of topological relationships of the models; then the distribution of topological relationships is used as features of the models, and the similarity between the features is calculated to measure the similarity of the corresponding 3D models.

Keywords: Extended drawing; polymorphic model; construction engineering; CAD modeling
DOI: https://doi.org/10.14733/cadaps.2022.S4.12-23

1 INTRODUCTION

Computer-aided design (CAD) is a new multidisciplinary and comprehensive technology that uses computer hardware and software systems to assist engineers and technicians in designing, modifying, displaying, and outputting products or projects [1]. The development of CAD technology can accelerate the speed of product development, engineering design technology, promote and realize intelligent labor automation and shorten the cycle of scientific research and engineering construction. Therefore, the development and application level of CAD technology has become one of the important symbols of a country's scientific and technological modernization and industrial modernization [2]. Collaborative engineering design needs to support all kinds of collaborative work in the whole life cycle of engineering design. These collaborative efforts include not only the collaborative work between the same professionals but also the collaborative work between designers of different professions. Engineering CAD drawings include 3D models and 2D drawings, and due to the complexity of various collaborative work in the whole life cycle of engineering design, different engineering CAD drawings need to be used for different stages. With the wide application of digital modeling technology, related enterprises and design institutes are keeping many digital engineering models, and the scale of the internal database of enterprises and design institutes will continue to grow as the development of enterprises and the number of projects increase [3]. In today's business competition, which is ultimately a competition of knowledge and technology, the generated engineering models are very valuable resources for enterprises. It is of great significance to improve the competitiveness of enterprises by effectively reusing existing resources, shortening the development cycle of new products, saving development costs, and improving the performance and quality of new products. Also, in the development of new products, the reuse of models can effectively improve the efficiency of designers and ensure the quality of models by drawing on existing design results [4]. Ivson et al. [5] studied the important role of reuse in the design of urban energy consumption models. They concluded that effective reuse of formalized knowledge can improve the efficiency of future modeling. Reuse plays an important role in model design for efficiency improvement and model quality assurance. To achieve design reuse, designers must first obtain reusable models, and local retrieval of 3D models is an important means to achieve this function. Sampaio [6] achieved the reuse of injection molding models through the local retrieval technique of models. Zhang first retrieve the candidate models that satisfy certain conditions, then filter the local models with higher similarity, and finally reuse these similar models. The experimental results showed that the reuse led to an improvement in the design efficiency of the injection molding models [7]. Ng and Chan [8] also realized the reuse of CAD models for CNC machining by the local retrieval technique of models. Kurz et al. [9] constructed a novel method to automatically generate high-precision stair paths that can support straight, spiral, and coiled stairs based on the topological network structure of different types of stairs in BIM models, making full use of the refinement features of BIM models. Daemei and Safari [10] construct an indoor real-time positioning system based on virtual reality (VR) of building information model (BIM) and applies it to crowdsourced fire detection in large scenes and public places, which can accurately and effectively simulate and supervise floor fire safety. With the continuous development and upgrading of UAV equipment, the wide application of five-lens photography range and multi-view photography has overturned the previous limitation that orthophoto can only be taken from a vertical angle, and the use of tilt photography to collect image data of ground scenes and rapid modeling has become a key technology for the construction of large-area real-world 3D models. Rapid modeling of UAV tilt image is to use multi-view and high overlap image data, and through the air three dense point cloud processing technology, according to the image coordinates of objects in the image and camera focus coordinates, match the calculation of the actual object point coordinates, and according to the corresponding coordinate system of features to build a real-world 3D model within the measurement range of features. The most common judgmental constraints are often manifested as declarative knowledge in the form of predicate logic, but there are also many constraints with preconditions. In this case, the constraint has a rule-like form including both the precondition and the content of the constraint. Also, there are special representations of some complex constraints. The above intelligent design methods are useful for guiding the research of intelligent design of process plants. The process plant model contains many design rules and constraints, so the above-mentioned rule-based intelligent design methods and constraint satisfaction-based intelligent design methods are theoretically applicable to the intelligent design research of process plants. However, since the plant design rules and constraints between components exist implicitly in the model, and many design rules exist but have not been refined into a text, it is necessary to use relevant methods of data mining to extract relevant rules and constraints from the large-scale historical model. Therefore, as a preliminary study of intelligent design in the field of engineering CAD, this paper will combine the relevant ideas of data mining knowledge to try to extract the implicitly existing design rules from the historical models, and then realize the intelligent prediction in process plant design through the idea of rule-based intelligent design.

2 ANALYSIS OF EXTENDED DIAGRAM AND POLYMORPHIC MODEL MODELING OF CONSTRUCTION PROJECTS

2.1 Extension Diagram and Polymorphic Model Design

In the whole lifecycle of a construction project, a model system is needed that can combine all the building information including construction, building, operation, and maintenance, etc. This model not only generates 2D CAD drawings to meet the design requirements but also changes all the corresponding dimensional annotations, progress plans, and other information when the model is modified. According to unified standard for building information model application, BIM is the general term for the process and results of designing, constructing, and operating a construction project by digitally expressing its functional and physical characteristics throughout its life cycle. Unlike the two-dimensional based modeling approach, the parameters and model are interrelated in the BIM-based modeling process, and when the parameters are modified, it will drive the model to change, and accordingly, if the model changes, its related parameter values will also be changed. On the one hand, the flexible and controllable system avoids a lot of repetitive work caused by the program modification; on the other hand, its WYSIWYG feature facilitates to view the contradiction of multiple systems in the construction process and coordinate well with each profession. From the application principle and method, parametric technology is not a necessary condition for the use of BIM technology, and BIM technology can be achieved without parametric, but from the analysis of the convenience of modeling operation, software processing speed, the complexity of system platform interaction, etc., at present, the use of BIM parametric modeling technology to the better and more comprehensive realization of the application of BIM effect, as shown in Figure 1 shows.

In contrast to the traditional 3D-based modeling approach, the basic principle of parametric modeling is to convert all the factors that control the generation of forms into function variables, and to convert the form generation logic into algorithms or function relationships, and to drive the algorithms to generate various forms by changing the function variables, whose focus is not on the geometric forms themselves, but on the logical laws that control the generation of geometric forms. In the case of heterogeneous surfaces, the modeling process is mainly to establish a logical algorithm that writes the required function variables into the algorithm to drive the algorithmic procedure to generate different surface forms. The fundamental purpose of parametric modeling is to establish the same class of geometries with common characteristics, rather than designing for a specific geometry, and by modifying the control parameters, multiple similar but not identical geometries can be obtained for later deepening and implementation. The use of parametric variables and algorithmic procedures to generate 3D models is more accurate and faster than traditional manual modeling, which can realize model linkage at any time and greatly improve modeling efficiency.

Currently, the approach of relying on parameter-driven model generation is mostly used in early conceptual design, by finding the logical basis or mathematical model to solve a specific design problem, and adjusting the overall model by changing and adjusting the logical parameters. Shaped buildings usually have many non-standardized skins and complex structures, which cannot be put together utilizing axial network positioning. The traditional modeling method of wearing the shape of the pieces through points, lines, and surfaces can hardly meet the requirements of dynamic and multi-dimensional forms of shaped buildings, and the shaped components not only make the architectural design and drafting more difficult, but also present a lot of difficulties when cooperating and coordinating with other professions, requiring more precise operations. Therefore, accurate modeling is crucial, and the use of parametric methods of modeling can better meet the construction requirements of shaped buildings.

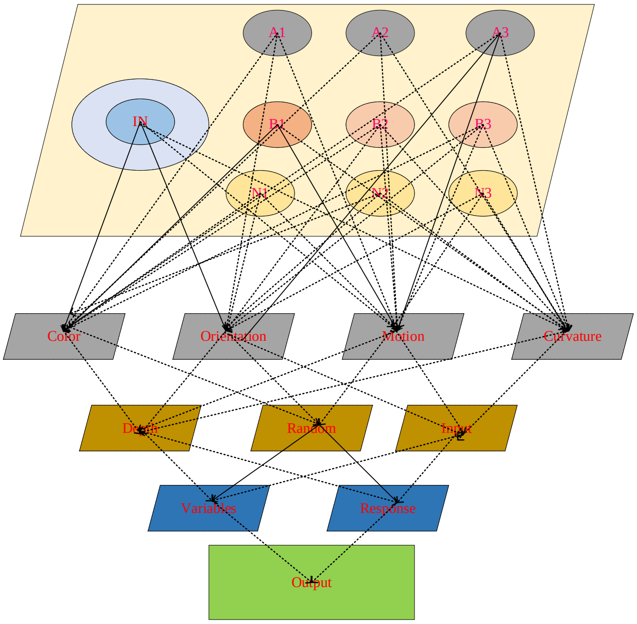

Figure 1: Extension diagram and polymorphic model.

For the location service-oriented extraction of ubiquitous information elements in this study, the whole elements of building entities are mainly granulated into two categories: simple texture geometry and complex texture geometry for data extraction and organization. The simple texture geometric structures mainly include doors, windows, walls, etc. of building information with uniform texture structure and a large number of reproducible geometric structure attributes, while the complex texture geometric structures can be rendered at a later stage to restore the texture style of the scene more realistically, mainly including display boards, door signs and other geometric structures containing complex textures of building elements.

$$f_0(x) = \arg\max_c \sum_{i=1}^{M} L\left(x_i, c\right) \tag{1}$$

In data mining techniques, association mining can discover association patterns hidden between data items, and the mined rules can also be used to predict unknown association relationships. Many building blocks in a processing factory often appear in pairs in the form of combinations, so association mining can be combined with process factory design to mine the implicit association design rules in the model. In the subsequent design, the prediction can be provided by applying the above mining results, which not only narrows the designer's choice but also helps to improve the modeling efficiency.

$$R_{im} = -\left[\frac{\partial L\left(x_i, f_i(x_i)\right)}{\partial f_i(y_i)}\right]_{f(x)=f_{m-1}(x)} \tag{2}$$

For the global similarity problem of the process plant model, a similarity measure algorithm based on the distribution of topological connection relations is proposed. The algorithm takes the distribution of topological connection relations as a feature of the model. To obtain this feature, a relationship tree model is first proposed, and the corresponding relationship tree is built by traversing the attributes and topological connections of each component to count the types and numbers of topological connection relations.

$$R_{jm} = \arg\max \sum_{x_i \in R_{jm}} L(x_i, f_{m-1}(\mathrm{y}_i) + \delta) \tag{3}$$

Second, feature unification is performed to map the number of topological connectivity relationships in their respective models to their respective spatial vectors, forming the feature vectors used to calculate similarity.

$$f_m(\mathrm{y}) = f_{m-1}(\mathrm{y}_i) + \sum_{i=1}^{J} R_{jm} I(R_{jm}) \tag{4}$$

Finally, a hybrid eigenvector similarity calculation function is proposed by combining the directional and numerical differences of the eigenvectors, and its calculation results are used to measure the plant model similarity.

$$f(\mathrm{y}) = f_M(\mathrm{y}) = F_0(y) + \sum_{i=1}^{J}\sum_{i=1}^{J} R_{jm} I(R_{jm}) R_{jm} I(R_{jm}) \sum_{i=1}^{J} R_{jm} I(R_{jm}) \tag{5}$$

The experimental results show that the calculation results of the global similarity metric algorithm based on the distribution of topological connection relations are in line with the actual situation, and there is a more obvious degree of differentiation between the metric results of homologous and heterologous models.

With the above events, we can see that intelligent data analysis systems offer another novel way of understanding the game that challenges, and to some extent replaces, traditional methods of team data analysis. The Sportive system can track each player's movement on the court, something that traditional data analytics would have struggled to do anyway. The improved access to information brings with it a huge amount of data processing.

$$f_T = \chi(W_f \cdot [H_0 X_1] + b_m) \tag{6}$$

The smart line model of the component consists of smart lines and key points. The key points of the component are the abstraction of the end face of the component and the key parts inside the component (such as the center of the circle and the external tangent point of the elbow arc segment), and the key points can be the pair of points defined in the previous section; while the smart lines are the abstraction of the overall shape of the component.

2.2 CAD Modeling Design of Building Engineering

The real-world information reconstruction method for indoor-outdoor integrated holographic maps of buildings is a logical organization system and physical storage structure for all-elements texture information and semantic attribute information of indoor-outdoor scenes summarized by combining UAV tilt photography measurement data and cell phone indoor all-elements data with geometric structure information based on BIM model lightweight. The main process includes three parts of texture information extraction, texture data representation, and attribute information organization. To improve the accuracy of texture rendering and better restore the indoor and outdoor scenes of buildings, semantic classification and corrective transformation processing of texture materials are required. In this paper, firstly, pre-processing operations such as radiation correction and field-of-view adjustment are performed on the original remote sensing image. Secondly, the position and pose information of the photos are obtained by smart mobile devices and light small UAVs, and finally, corner point detection and perspective transformation are performed by computer image processing techniques to obtain the vertex coordinates and orthophoto maps of texture maps with different orientation and attribute information.

In the field of general-purpose or product CAD, researchers mostly judge the similarity of models from the perspective of geometric shape. This is mainly because human beings are accustomed to judge the similarity of objects from the perspective of shape, and the models of the general-purpose domain and product CAD models focus on the accurate representation of object geometry and dimensions when modeling, so the similarity measure of such models naturally focuses on a geometric shape. However, in the engineering CAD field, if the CAD models describe the same engineering project, they should have a high similarity, even though they may differ in content structure, drawing scale, and graphical representation. Since the focus of engineering CAD models is on the accurate expression of topology among components, and all kinds of CAD models describing the same engineering project are consistent in the topology they maintain, the similarity of heterogeneous engineering CAD models can be determined concerning the following principles: if the topological features of the comparison models are exactly similar, indicating that the topology expressed by both is the same, they are considered similar; if the topological features of the comparison models are partially similar, it indicates that the smaller model in the comparison model may be the local description of the larger model, so they are also considered similar; if neither of the above two cases is satisfied, the comparison models are considered dissimilar, as shown in Figure 2.

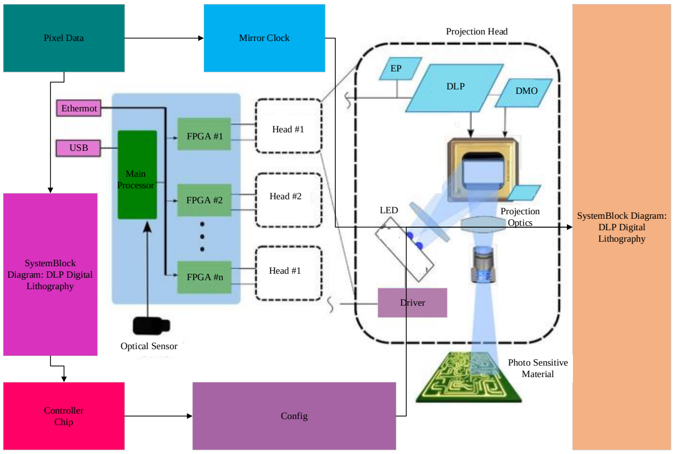

Figure 2: CAD modeling of building engineering.

First, the topology-based model unification representation proposed in this chapter helps to ensure the accuracy of the similarity calculation of engineering CAD models. Since the topology is the core of engineering models, the similarity measure of engineering models should focus on the topological connection relationship between components. In the process of generating attribute diagrams for heterogeneous engineering CAD models, the non-core information, such as geometric information and annotation information, is removed by traversing the model containing complex information once; at the same time, the core information of engineering models, such as attribute information of components and topology structure between components, can be obtained, which ensures the correct representation of the generated attribute diagrams to the original engineering. This ensures the correct expression of the generated property diagram to the original engineering model, which in turn helps to improve the accuracy of similarity calculation of engineering CAD models.

Secondly, the model representation method proposed in this chapter helps to improve the efficiency of the similarity calculation of engineering CAD models. The traditional model representation method based on geometric shape represents the original model by extracting the geometric information of the model, so the data size of geometric information will directly affect the efficiency of subsequent similarity calculation. The larger the amount of geometric information is, the longer the computation time will be. In contrast, the topology-based model representation method uses the topology between components to represent the corresponding model, so its similarity computation time is related to the number of topological relations. The more the number of topological relations, the more the computation time increases. In the engineering CAD model, the solid shape of the components is represented by the face pieces. Table 1 counts the number of components, topological relations, and face pieces of the model. The data in the table shows that the sum of the number of components and the number of topological relations of each model is much smaller than the number of facets. This indicates that the number of geometric information in the engineering CAD model is more than the number of topological information, so the calculation time of similarity based on geometric shape is relatively longer to some extent. Therefore, compared with the geometry-based model representation, the topology-based representation is more helpful to improve the similarity calculation efficiency of the engineering CAD model.

Model	Number of components	Number of topological connections between components	Number of doughs
A	15	15	147
B	14	42	475
C	75	142	124

Table 1: Statistics of topological and geometric information of the model.

The global similarity measure of the 3D model, the local similarity measure of the 3D model, and the similarity measure between 2D engineering drawing and 3D model. Therefore, a global similarity metric algorithm based on topological relationship distribution is introduced first, then a local retrieval algorithm based on edit distance is introduced, and two topology-based similarity metrics between 2D engineering drawings and 3D models are introduced in Chapter 3.

3 ANALYSIS OF RESULTS

3.1 Extended Graph and Analysis of Polymorphic Results

In this section, the flow direction is chosen as the attribute identifier of the edges for the experiments. First, the relationship tree is constructed for each model with the typical attributes of each component in the model as the main identifier of the tree nodes; after that, the feature vectors of the models can be obtained through the relationship tree, and then the two models compared are feature unified according to the method shown; finally, the similarity calculation function shown is used to calculate the similarity between the models shown in Figure 3 respectively. The results are compared with those of the classical angle cosine method. Since the retrieval efficiency of the above algorithm is affected by the random numbers generated in the algorithm, the results of 100 retrievals of the model to be retrieved under different thresholds in the historical model library are synthesized.

Figure 4 shows the size of the historical models and the number of relevant local models in the historical model library, and the search rate and accuracy rate of the search results under different thresholds are calculated by combining all the search results.

Figure 4 shows the retrieval details of a representative number of retrieval results. The average number of traversals is the average number of times the model to be retrieved was traversed when a retrieval result was obtained, and the similarity is the degree of similarity between the retrieval result and the model to be retrieved.

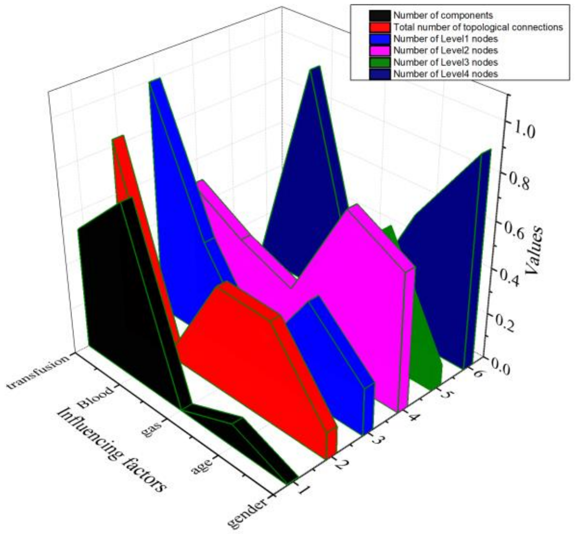

Figure 3: Scale of each model and relationship tree information statistics.

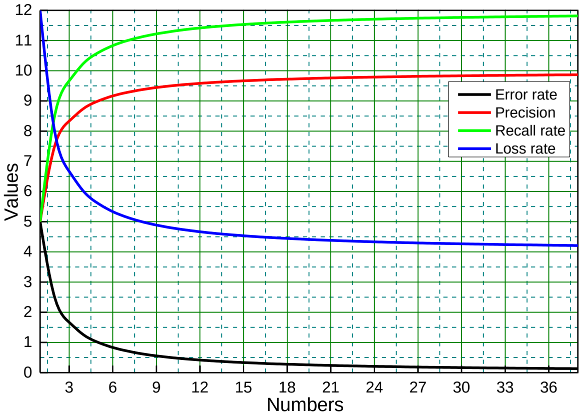

Figure 4: Statistics of attribute map generation results of the model.

The algorithm uses the type of the component as the main identifier of the attribute map nodes, which can reduce the complexity of local retrieval of 3D models. Compared with the geometric shape of the model, process plant designers pay more attention to the topology of the model, and the type name field in the database is an important basis for designers to discern whether the selected component is the target type component in the modeling process. Therefore, in the process of converting the process plant model into an attribute diagram, the geometric information of the components is replaced by the component type, which makes it possible to skip the tedious geometric feature extraction and similarity comparison in the subsequent model similarity metric, which not only simplifies the complexity of model local retrieval but also obtains retrieval results similar to the model to be retrieved, as shown in Figure 5.

The edit distance-based local retrieval algorithm for process plant models is a heuristic algorithm. By setting the edit distance threshold, the algorithm can get the matching models within the acceptable range of the user in a limited time. This fuzzy query set by the user can undoubtedly improve the computational efficiency of local retrieval so that the algorithm still has good retrieval performance when retrieving process plant models containing more than tens of thousands of components.

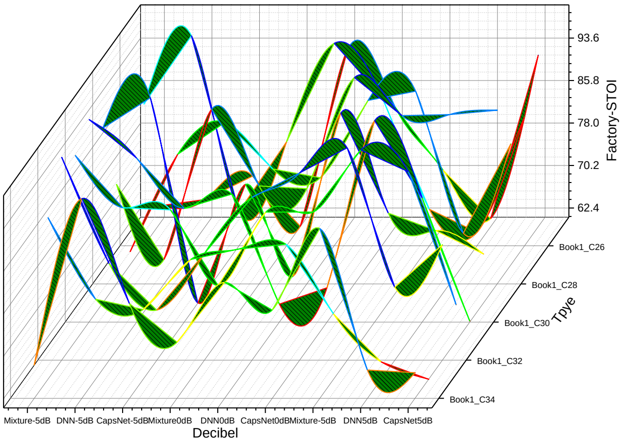

Figure 5: Sensitivity of Logistic mapping to initial values.

3.2 Analysis of Modeling Results

Figure 6 shows the (correctness/recall/precision plots of the model hash-based similarity metric for different attributes. As can be seen from the figure, the three-evaluation metrics change similarly to the change of p-value. The precision of the model hash-based similarity calculation method also remains at a low level when the attribute is selected as flow direction. In contrast, when the attribute is selected as the insertion point coordinates and his value is between 0.83 and 0.9, the three evaluation indexes of the method are at a high level, and the combined level of the three evaluation indexes reaches the highest level at (0.89, indicating that the method has the best retrieval performance in the current situation.

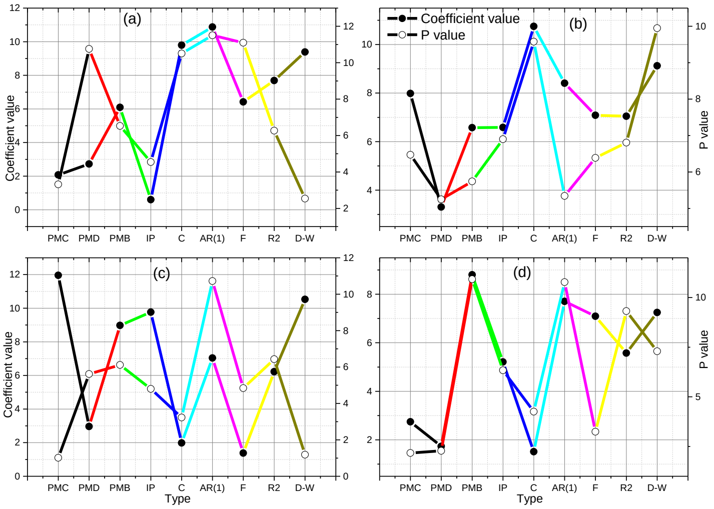

Figure 6: Values of model hash-based similarity measures under different attributes.

Most of the cases have high computational time efficiency. The model hash-based similarity calculation method first generates a fixed-length hash value for each model, and then the hash value can be used as the index of the model. In the process of similarity calculation, if the scale is the same, there is no need to calculate the hash value again and the similarity calculation can be performed directly; if the scale is different, it is only necessary to calculate the hash value of the larger model again. Since the hash lengths of all models are equal, their similarity calculation time is not affected by the feature size in most cases, as shown in Figure 7.

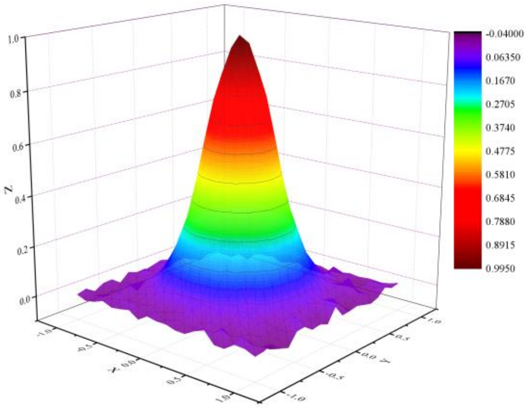

Figure 7: Face grid line generation.

The front and back curtain wall surfaces are meshed using the custom node "Iso-structure line division" to divide the UV mesh, where the input surface is the surface and the UV end indicates the direction of the structure line division. In this project, the surface is divided into 20 *50 blocks according to the required range of panel cell size, and an adaptive UV dotted surface is generated. In this project, in addition to the independent positioning number of each panel, the main information also includes dimension markings, panel ID number, member model, manufacturer, installation batch, etc. All the curtain wall panel families are extracted in Dynamo, and the shared parameters are added in batch in the member property column to avoid the time-consuming problem of adding them repeatedly by hand. Category node to get the panel family that needs to add parameters, the parameter name is defined by Code Block, and the main parameters are written by Parameter.

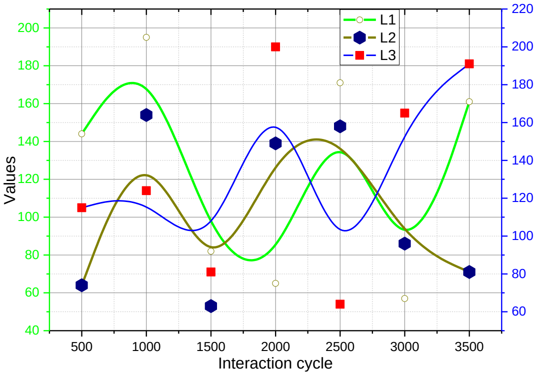

Figure 8: Curtain wall component information output.

In this project, Dynamo was used to generate the outer skin of the roof and curtain wall, and the external contour lines were constrained through the point-line surface linkage, and then the contour lines were released to generate the surface, and they were passed to Revit to generate the solid model, and the geometric logic parameters controlling the surface generation were also retained on the model. This improves the traditional workflow of modeling in parametric software and then importing into Revit environment to rebuild a solid model, and realizes the transfer of logical parameters.

4 CONCLUSION

This paper proposes a multi-source high-dimensional data integration method based on the semantic classification of all indoor and outdoor elements of buildings and the location-based multi-grained ubiquitous information aggregation, and realistic data organization by texture material and geometric model semantic matching and texture rendering to realize the visual representation of indoor and outdoor integrated realistic holographic maps of buildings. The architecture mainly consists of two aspects: location-based multi-grained ubiquitous information modeled and encapsulated storage and Web service-based indoor-outdoor integrated realistic holographic map visualization interaction. Based on this approach, a mobile visualization system of multi-granularity holographic maps of buildings is designed. The empirical evidence shows that the model constructed in this paper has key node coordinate information, structural-semantic information, and real scene information of buildings, supports cross-platform and multi-terminal mobile Internet applications, provides richer and more refined base map data for joint indoor-outdoor applications of buildings and provides high map data use and reference value for location service-based building map applications.

Qiang Xie, https://orcid.org/0000-0002-3867-329X

REFERENCES

[1] Lin, J.-W.; Shen, P.-F.; Lee, B.-J.: CAD of human resource configuration in project scheduling for construction engineering applications, Computer Applications in Engineering Education, 26(5), 2018, 1255-1269. https://doi.org/10.1002/cae.21999

[2] Cuillière, J.-C.; François, V.; Nana, A.: Automatic construction of structural CAD models from 3D topology optimization, Computer-Aided Design and Applications, 15(1), 2018, 107-121. https://doi.org/10.1080/16864360.2017.1353726

[3] Su, Z.; Ye, Y.; Zhang, Q.; Li, W.; Dai, Y.: Robust 2D engineering CAD graphics hashing for joint topology and geometry authentication via covariance-based descriptors, IEEE Transactions on Information Forensics and Security, 13(4), 2017, 1018-1030. https://doi.org/10.1109/TIFS.2017.2777341

[4] Xie, C.; Schimpf, C.; Chao, J.; Nourian, S.; Massicotte, J.: Learning and teaching engineering design through modeling and simulation on a CAD platform, Computer Applications in Engineering Education, 26(4), 2018, 824-840. https://doi.org/10.1002/cae.21920

[5] Ivson, P.; Nascimento, D.; Celes, W.; Barbosa, S. -D.: CasCADe: A novel 4D visualization system for virtual construction planning, IEEE transactions on visualization and computer graphics, 24(1), 2017, 687-697. https://doi.org/10.1109/TVCG.2017.2745105

[6] Sampaio, A.-Z.: BIM as a computer-aided design methodology in civil engineering, Journal of Software Engineering and Applications, 10(2), 2017, 194-210. https://doi.org/10.4236/jsea.2017.102012

[7] Zhang, H.-Z.; Xie, C.; Nourian, S.: Are their designs iterative or fixated? Investigating design patterns from student digital footprints in computer-aided design software, International Journal of Technology and Design Education, 28(3), 2018, 819-841. https://doi.org/10.1007/s10798-017-9408-1

[8] Ng, O. L.; Chan, T.: Learning as Making: Using 3D computer-aided design to enhance the learning of shape and space in STEM-integrated ways, British Journal of Educational Technology, 50(1), 2019, 294-308. https://doi.org/10.1111/bjet.12643

[9] Kurz, S.; Schöps, S.; Wolf, F.: Towards a spectral method of moments using computer aided design, Advances in Radio Science, 17(B.), 2019, 59-63. https://doi.org/10.5194/ars-17-59-2019

[10] Daemei, A.-B.; Safari, H.: Factors affecting creativity in the architectural education process based on computer-aided design, Frontiers of Architectural Research, 7(1), 2018, 100-106. https://doi.org/10.1016/j.foar.2017.09.001