A Topological and Hierarchical Information Integration Approach for Standard-unit-based Residential Planning

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Abstract:

Standard-unit is a residential design template which is concluded from flats sharing the same layout, similar decorating style, and same kind of furniture and appliances. Conventional way to implement standard-unit is to use standard design drawings. Such drawings are mainly kept as hard-copies or CAD digital files, which lacks semantic information and makes it difficult to fully utilize the standard-units. Building Information Model/Modeling (BIM) technology provides a solution to enhance the implementation of standard-unit. In this study, we first developed a series of algorithm to extract semantic, topological and hierarchical information from IFC-files. Then a topological and hierarchical information integration approach was proposed for standard-unit-based residential planning. A prototype database and modeling system were also developed to demonstrate this approach. Both the database and modeling system were tested with real project data. The application indicates that the proposed approach can efficiently integrate topological and hierarchical information in the residential project.

Keywords: BIM, IFC, Topological information, Hierarchical information, Information integration, Residential plan.

1. INTRODUCTION

For ordinary residential buildings, design work is tedious and time-consuming. Especially for those flat apartment with same or similar floor plans. As a result, designers have created standard designs to accelerate the design process. Most residential standard designs are for floor plans or room layouts, which is also called as ‘standard-unit’ in China. Being used as a residential design template, standard-unit is usually concluded from flats sharing the same layout, similar decorating style, and same kind of furniture and appliances, containing geometric, economic and ecologic design information. For those standard-units gathered from as-built projects, they also contained construction and maintenance information. The rich information of standard-units give us an advantage to reuse the design and make creating new residential plans much quicker.

However, conventional way to implement standard-unit is to use standard design drawings, which are mainly kept as hard-copies or CAD digital files. Such way of utilization lacks information integration, especially lacks integration of topological and hierarchical information which are important in different kinds of analyses and simulations. Therefore such implementation makes it difficult to fully use the standard-units.

Building Information Model/Modeling (BIM) technology provides a solution to enhance the implementation of standard-unit. BIM as product models or a process which supports information integration and utilization are becoming more and more widely used in the AEC industry. Functioning as a single data repository, BIM is capable of storing and integrating information coming from different sources, which may help to improve the integration level of standard-unit.

In this study, we first developed a series of algorithm to extract semantic, topological and hierarchical information from IFC-files. Then a topological and hierarchical information integration approach was proposed for standard-unit-based residential planning. A prototype database and modeling system were also developed to demonstrate this approach. Both the database and modeling system were tested with data from real estate projects.

2. RELATED WORKS

Standard-unit is a concept coming from residential industrialization. Current researches regarding industrialization were mainly about prefabricated components or modular buildings etc., which are mostly applications from fabrication to construction phase during the building life cycle. On the contrary, there was few researches focus on the early design stage of industrialized residential buildings. As early design stage is the most flexible phase when plans are free to justify with low cost, more and more researchers have emphasized that there was a strong need of redistribution of efforts towards early knowledge integration and computational support (Wang et al., 2002 and Cavieres et al., 2011).

However, there have been a lot of related works concerning topological and hierarchical information integration and usage during early space design. To assure a semantically rich and structurally correct floor plan in the design process, Choi proposed a concept of structured floor plan (Choi, et al., 2007). Such model consisted components such as wall skeletons and spaces, and also could automatically update topological and hierarchical information as the model changed. Based on this structural floor plan, a system named GongPath for way-finding was developed by combining BIM technology with space subdivision algorithms (Lertlakkhanakul et al., 2009). A methodology named orthogonal compartment placement (OCP) was presented focusing on the arrangement of rooms or compartments based on topological reasoning (Regateiro et al., 2012). This method was a computational approach which tries to generate feasible layout that were topologically distinct. ONALIN was another ontology-based algorithm that provided routing for individuals (Dudas et al., 2009). The ontology took the American Disability Act (ADA) standards, and the algorithm could help user select most comfortable routes among alternatives provided by the software with respect to the special needs of the users.

For design of residential industrialization and reuse of as-built projects, Diez developed an automatic modular construction software environment named AUTOMOD3 to generate trajectories which can be applied to robotized crane development (Diez et al., 2007). Langenhan proposed a method called semantic fingerprints of buildings which is a sketch-based search strategies for indexing spatial configurations (Langenhan et al., 2013). This method can help user search for semantically similar floor plans by extracting the semantic structure and comparing them with graph matching. Based on the building fingerprint, Ahmed developed a system called a.SCatch to make access to knowledge from past projects more easily (Ahmed et al., 2014). Daum presented a query language QL4BIM which also based on building fingerprints. QL4BIM provided high-level topological operators to efficiently retrieve accessibility and adjacency relationships (Daum et al., 2015).

This research tried to introduce topological and hierarchical information integration to enhance the efficiency and quality of the industrialized residential design.

3. STANDARD-UNIT INFORMATION EXTRACTION

As mentioned before, standard-unit should be stored and used as a BIM. In this research, we developed an IFC-based information retrieval interface. IFC schema has definitions for representing all semantic, topological and hierarchical information. For semantic information, we tracked down the attributes and related property sets in entities, including IfcWall, IfcWallStandardCase, IfcWindow, IfcDoor, IfcSpace and IfcFurnishingElement, and their corresponding types such as IfcWallType, IfcDoorStyle, IfcWindowStyle, IfcFurnishingElementType.

Then the geometrical information were deeply examined to determine topological and hierarchical relationship between spaces, such as rooms, flats and floors. These 3 kinds of spaces were then used to construct the whole residential plan as elementary components. Hierarchical information can be retrieved according to the IfcRelAggregates relations. However, there are 2 problems that thwart retrieving correct information. First, IFC schema has defined the IfcSpace directly contained by IfcBuildingStorey, which makes discerning of flat (space comprising several rooms and generally living with one family) or room very difficult. Second, Autodesk Revit does not allow that one room inside another room, which also makes entities defined as flat are lost in exported IFC files. To solve these problems, we developed a plugin for Autodesk Revit to define flats.

Comparing to hierarchical information, topological information can retrieved directly from IFC file. But it also needs some special treatment. There are two kinds of relations between two spaces in residential building which are adjacencies and accessibilities. Adjacencies are defined by rooms with same wall as their co-boundary, which can be found by the relations between IfcSpace, IfcRelSpaceBoundary and IfcWall (or IfcWallStandardCase). Such determination of adjacency requires that the wall has been separated to ensure that one wall is the only boundary of at most two rooms. However, IFC files exported by Revit do not meet the requirements most of the time. Therefore, we had to determine whether two rooms have the same wall as their boundary are really adjacent to each other. And for accessibilities, it is same in determining whether two spaces are adjacent. The only difference lies on if there is a door connecting them. This requires information retrieved from IfcRelVoidsElement, IfcOpeniningElement and IfcDoor. In this research, topological information are recorded only among spaces in the same hierarchical level (will be explained in 4.2). Spaces between different hierarchical levels such as a flat with a room, their topological information will not be recorded even they are adjacent or accessible to each other. This is a way to reduce data redundancy, as topological relations with different levels can always expressed as topological relations with the same hierarchical level. The IFC-based retrieval of topological information are showed in Fig 1.

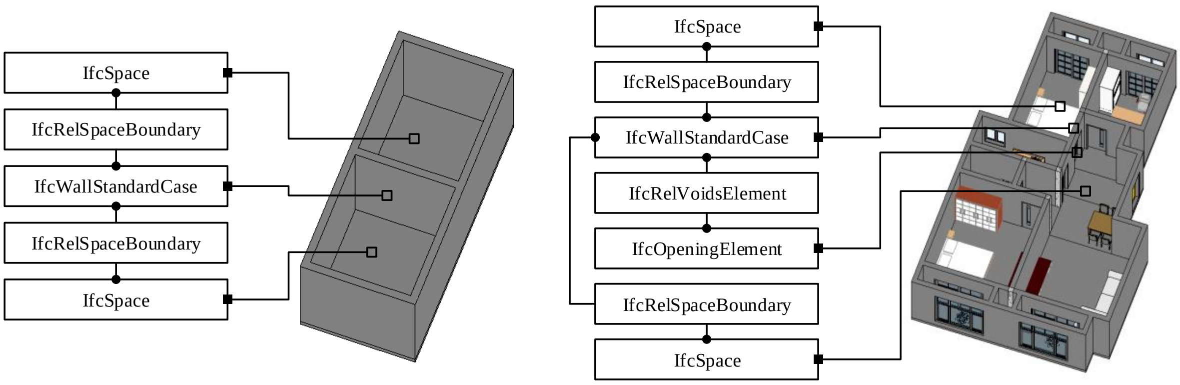

Figure 1. Retrieval of topological information based on IFC

The IFC files of standard-unit is provided by Autodesk Revit 2016. Fig 2 is an example of the topological and hierarchical information retrieval, which are displayed as plan view and topology view. The semantic information and 3D model are also demonstrated in corresponding views. After the information retrieval completed, we stored both IFC file and retrieved information into a relational database.

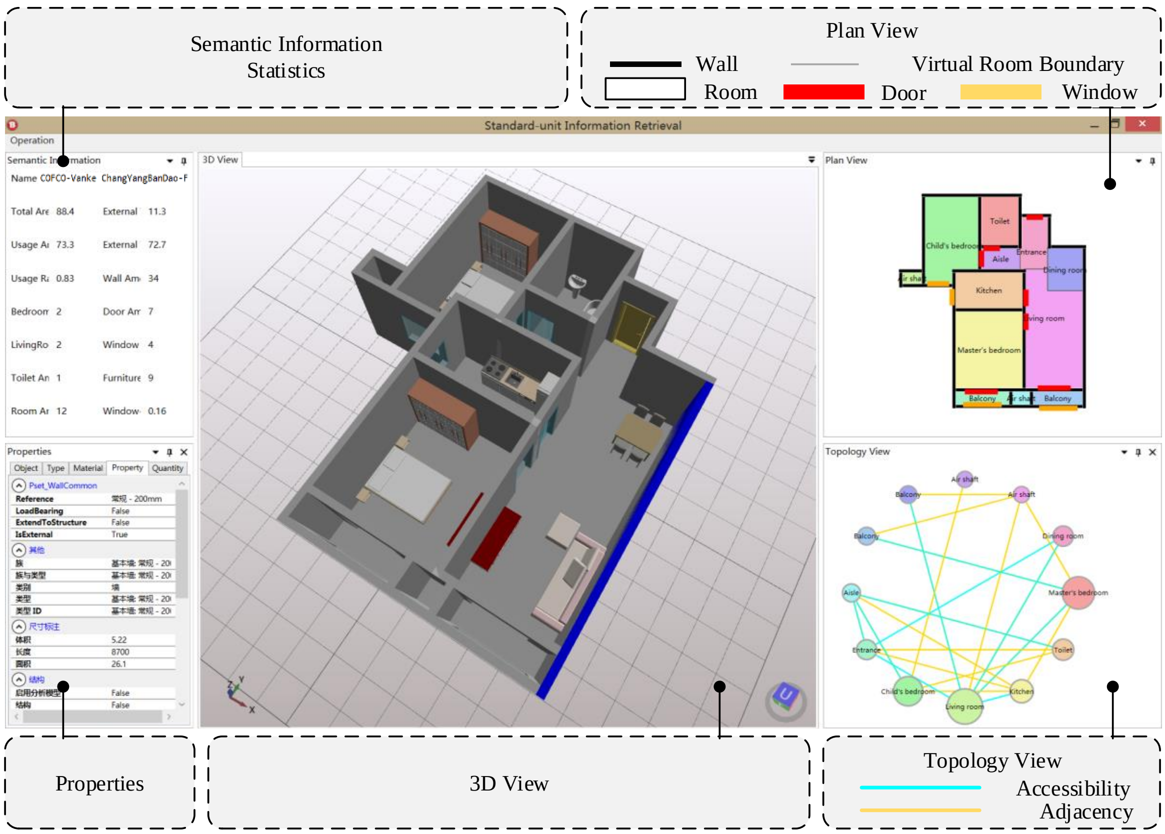

Figure 2. Display of the result of topological and hierarchical information retrieval

4. PLAN MODELING AND INFORMATION INTEGRATION

4.1 Standard-unit-based modeling procedure

Residential plan BIM can be decomposed into standard-units. Therefore, we has proposed a standard-unit-based fast modeling procedure (He et al., 2014). This procedure consist four main steps: 1) Retrieve information from the IFC files of standard-units. Manage those information and ifc model with database. 2) Select and load standard-unit BIMs into one project whose requirements in turn guide user to modify standard-unit model. 3) Comprise several standard-unit to create a building template. 4) Arrange building templates and roads to create whole residential plan.

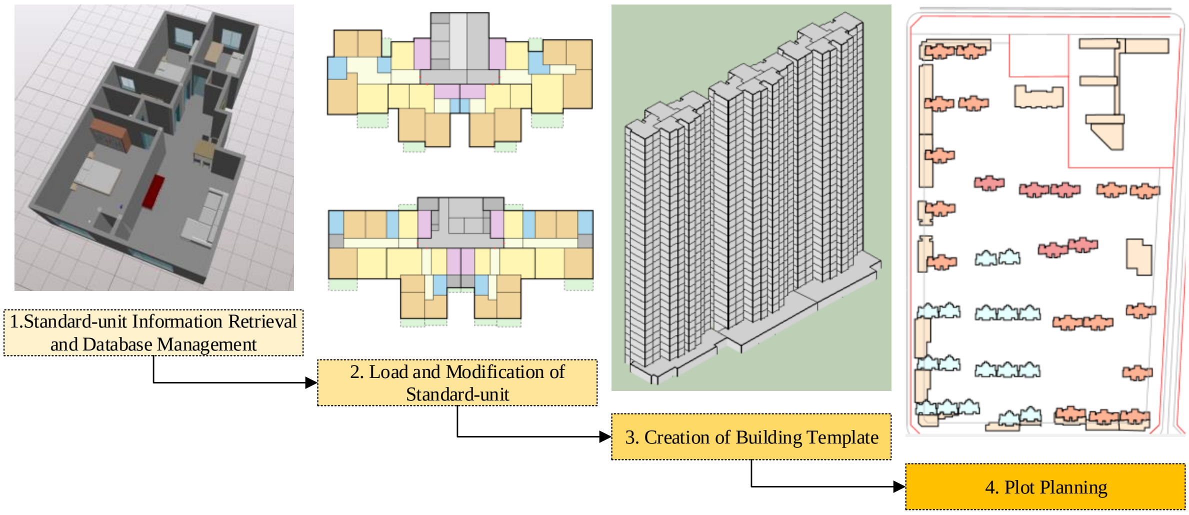

Figure 3. A standard-unit-based fast modeling procedure

4.2 Framework for residential plan information integration

According to the modeling procedure mentioned before, we also proposed a structure and corresponding process for residential plan information integration. Fig 4 and Fig 5 have showed the topological and hierarchical relations of a residential plan model.

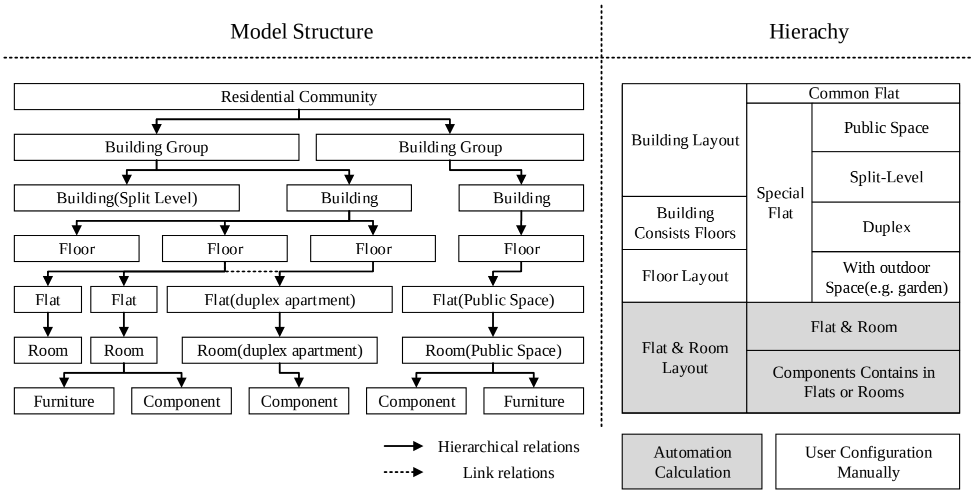

Figure 4. Hierarchical relations of a residential plan model

Hierarchical structure of residential plan model is a tree structure. Fig 4 shows the affiliations among one residential project, which is divided into 7 levels. From top to bottom, the 7 levels are residential community, building group, building, floor, flat, room, and furniture or component respectively(a standard-unit can be either a flat or a floor). Each node can possess arbitrary number of child nodes which belong to the one-level-lower level, while it can only be possessed by at most one parent node which belongs to the one-level-upper level. For example, one floor can be decomposed into 5 flat units, while it comprises the whole building along with other 14 floors. A floor cannot be directly decomposed into rooms. Of course there are exemptions, such as a lobby sharing 2 floor spaces in an apartment. In this situation, we consider this lobby to be a 'flat' which belongs only to one floor and is linked to other floors (show as dotted line with arrow connecting a floor with a duplex apartment flat in Fig 4).

During the standard-unit-based fast modeling procedure we mentioned before, hierarchical relations between each node are designed to be updated semi-automatically. For the lower 3 levels, flat, room and furniture, their hierarchical relations are retrieved by analysis of IFC file. For floor and building levels, relations are created and recorded as user modifying a standard-unit (first step of the procedure) and creating a building template (second step of the procedure). For building group level and special link relations such as duplex apartment, corresponding functions will be provided to help user defined them manually.

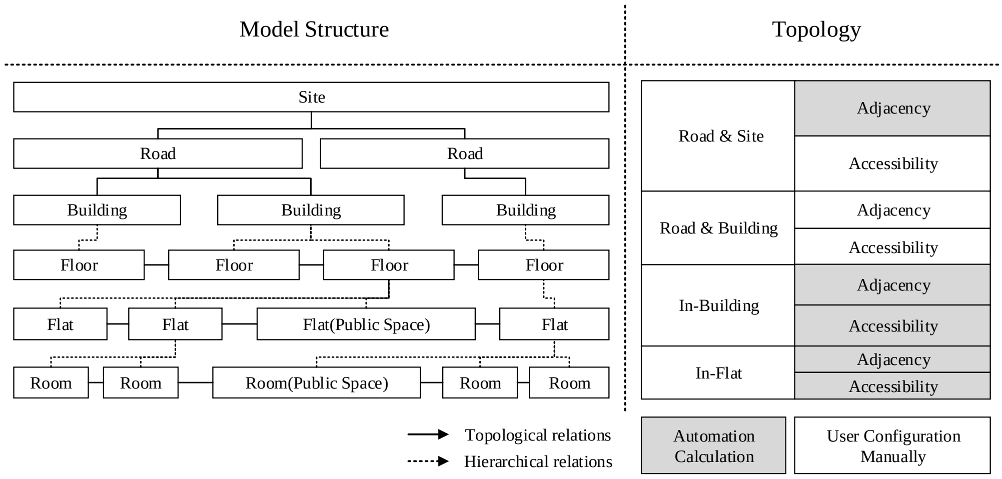

Figure 5. Topological relations of a residential plan model

Comparing to tree structure of hierarchy, topological structure is totally different. Topological structure of residential plan model is a graph structure. The nodes inside such kind of topological graph are also divided into 6 levels. The 6 levels are site, road, building, floor, flat and room respectively (a standard-unit can be either a flat or a floor). Except roads, other 5 levels can be mapped to hierarchical levels with one-one correspondence. Each node can linked to an arbitrary number of nodes. Nodes from floor, flat and room levels can only linked to nodes within the same level, while nodes from building, road and site levels can linked to each other freely as long as the linked nodes also belong to a building, road or site level. Topological relation can be either adjacency relation or accessibility relation. Topological information are stored with redundancy for convenience of data retrieval. Since topological relations of nodes from upper levels are decided by nodes from lower level, hierarchical relations is critical for the construction of topology model (Hierarchical relation are shown in dotted line with arrow in Fig 5). For example, 2 flats are adjacent because each them has one room that is adjacent to each other.

Similarly, topological relations are designed to be updated semi-automatically during the modeling procedure. For flat and room levels, their topological relations are retrieved by analysis of IFC file. For floor level, relations are automatically calculated and recorded as user modifying a standard-unit (first step of the procedure) and creating a building template (second step of the procedure). For building, road and site levels, relations will be automatically calculated or configured by user manually by offering user corresponding functions.

5. CASE STUDY

We developed a prototype database and a modeling system to support the application of the model and the information integration procedure. The prototype database is a stand-alone software using Microsoft WPF and ADO.NET technologies. The information retrieved from standard-unit IFC files are stored in a relational database. The modeling system has 2 parts: one is a plugin for Autodesk Revit 2016 which can build a residential plan from standard-unit step by step and persist the standard-unit in the database, the other is a stand-alone modeling platform which can not only create models but also do analysis and simulation. Both the database and modeling system were tested with open data from SouFang Website. Application of the standard-unit based residential plan model, especially the use of topological and hierarchical information, will be narrated in the following paragraphs.

6. Application

6.1 Plan similarity analysis and classification

For designers, a standard-unit database may become too big to use. A company may have hundreds or even thousands of standard-units. And for a city or a district, the number may surpass a hundred thousand. Traditionally, standard-unit were managed and searched by key information such as type number, project name and location etc. The results of such kind of method couldn't meet today's needs. In this research, we developed several algorithms to examine the similarity between standard-units. If the user gets interested in one standard-unit, other similar standard-units will be collected according their similarities (Fig 6).

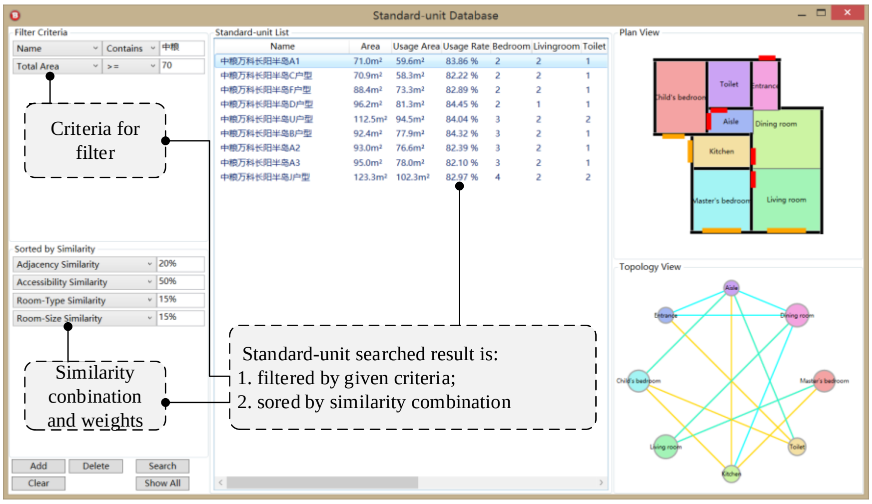

Figure 6. Standard-unit sorting according to similarity
(*In Chinese context, living rooms (*'Shi'*) also count for dining rooms and studies)

There are several different similarities as showed in the figure above, including room-type similarity, room-size similarity, accessibility similarity and adjacency similarity. Each similarity type can be used to sort standard-units independently. They can also be used together by assigning each similarity with a weight given by user.

All 4 kinds of similarity are calculated by comparing chosen standard-unit to others. Firstly, two of them are analyzed, transformed to two vectors respectively. As for room-type similarity, the dimension of the vector is equal to the total amount of room types in 2 chosen standard-unit, and each value of different dimension is defined by whether the room has the same room type. Thus, the value of each dimension will be either 1 or 0. Other 3 kinds of similarities are calculated in a similar way with slight differences. Fig 7 shows an example of the calculation of accessibility similarities between one standard-unit with another three.

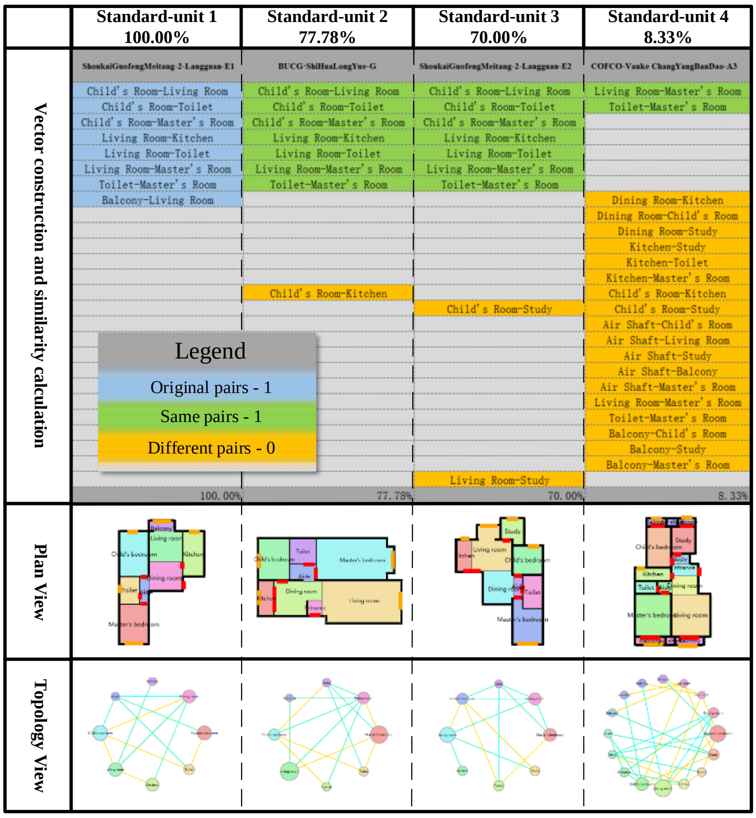

Figure 7. Example of accessibility similarity calculation

After the calculation of vectors, the similarity is calculated using vector distance. The farther their distance is, the less their similarity is. Distance calculation can be calculated by either Manhattan distance, Euclid distance or Tanimoto distance. Fig 8 shows the difference between different distance calculations where different number and color are used to represent different standard-unit. The results turn out that Euclid distance acts better than the other two.

0	COFCO-Vanke ChangYangBanDao-A1 ← List of standard-units sorted by similarity comparing to this standard-unit				
	Manhattan		**Euclid**		**Tanimoto**
1	COFCO-Vanke ChangYangBanDao-C	1	COFCO-Vanke ChangYangBanDao-C	1	COFCO-Vanke ChangYangBanDao-C
2	Longmai-A2	2	Longmai-A2	5	COFCO-Vanke ChangYangBanDao-U
3	COFCO-Vanke ChangYangBanDao-F	4	ShoukaiGuofengMeitang-2-Langguan-E1	3	COFCO-Vanke ChangYangBanDao-F
4	ShoukaiGuofengMeitang-2-Langguan-E1	3	COFCO-Vanke ChangYangBanDao-F	2	Longmai-A2
5	COFCO-Vanke ChangYangBanDao-U	5	COFCO-Vanke ChangYangBanDao-U	4	ShoukaiGuofengMeitang-2-Langguan-E1

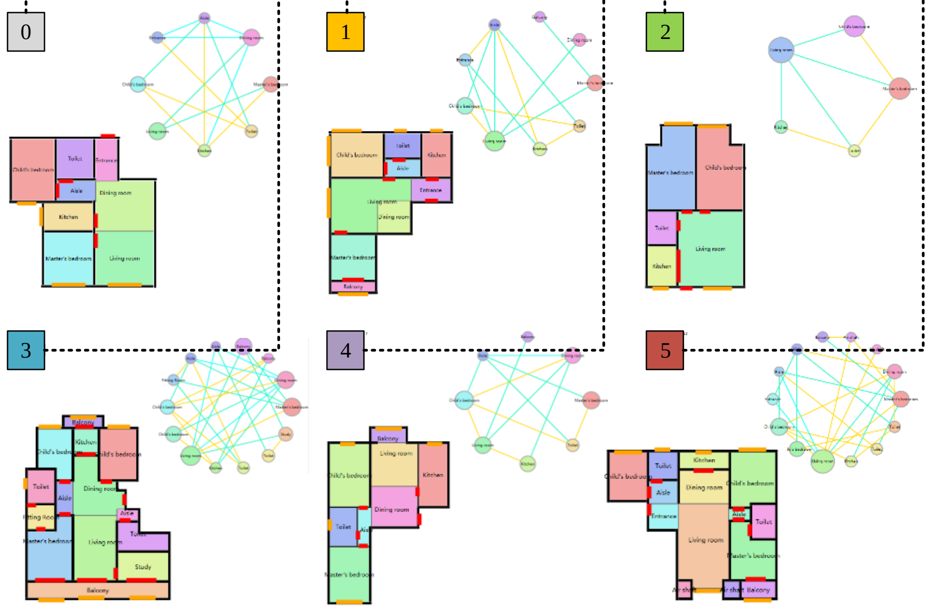

Figure 8. Comparison between similarity sorting results based on different distance calculation methods

6.2 Building performance simulation

Building performance simulation, such as daylight simulation, ventilation simulation, energy consumption analysis and feasibility analysis, requires accurate geometrical, material and other information. However, such information are quite difficult to retrieve in early design stage. Standard-unit from as-built projects can help solve this problem. We developed interfaces to support building performance simulation in other external BIM tools such as Autodesk Ecotect.

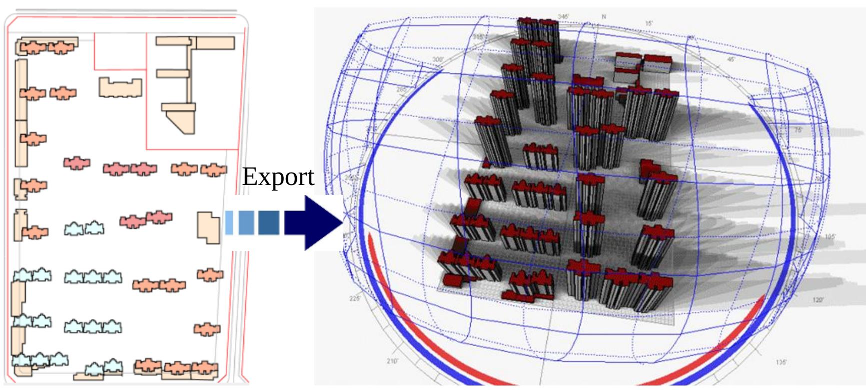

Figure 9. Daylight analysis simulation in Autodesk Ecotect using data exported from the modeling system

6.3 Future Application

As the hierarchical and topological information have greatly enhanced connections between various components in the residential plan model, the usage of information provided by standard-unit can be fully explored. There are several applications which are under process in this research projects:

a) Graph-based applications such as indoor navigation and evacuation simulation.

b) Optimization of building layouts. The optimization goal such as daylight hours or road length can be automatically calculated. The constraints are expressed by parametrically rules. Genetic algorithm and simulated annealing are used which support automatic or semi-automatic optimization.

c) Specification validation. Early design requirements concluded from clients, standards and etc. can also be expressed parametrically. User will be warned when any violation to specification happens.

7. CONCLUSIONS

To make full use of the rich information of standard-units, we first developed a series of algorithms to extract information from standard-unit BIMs. The retrieved information are well stored and managed as a standard-unit database. Then, we proposed a hierarchical and topological information integration approach for standard-unit-based residential planning. In this approach, the standard-units were used as components to build a whole residential plan model, when the hierarchical and topological structures are built up semi-automatically to strengthen the connections in the model. A prototype database and modeling system were also developed to demonstrate this approach. Both the database and modeling system were tested with data from real estate projects. The application indicates that the proposed approach could efficiently integrate topological and hierarchical information in the residential project, and would improve the efficiency and quality of the residential plan.

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REFERENCES

Ahmed, S., Weber, M., Liwicki, M., Langenhan, C., Dengel, A. and Petzold, F. (2014). Automatic analysis and sketch-based retrieval of architectural floor plans, *Pattern Recognition Letters*, 35(0): 91-100.

Cavieres, A., Gentry, R. and Al-Haddad T. (2011). Knowledge-based parametric tools for concrete masonry walls: conceptual design and preliminary structural analysis, *Automation in Construction*, 20, 716-728.

Choi J W and Park J W. (2003). Building data model and simulation platform for spatial interaction management in smart home, *Proceedings of 8th International the International Building Performance Simulation Association Conference*, 17(8): 11-14.

Daum, S., Borrmann, A., Langenhan, C. and Petzold, F. (2015). Automated generation of building fingerprints using a spatio-semantic query language for building information models, *Proceedings of 10th European Conference of Product and Process Modeling*, 87-94.

Diez, R., Padron, V.M., Abderrahim, M. and Balaguer, C. (2007). An investigation into the applicability of building information models in geospatial environment in support of site selection and fire response management processes, *International Journal of Advanced Robotic Systems*, 4(4) 457-468.

Dudas, P. M., Ghafourian, M. and Karimi, H. A. (2009). ONALIN: Ontology and algorithm for indoor routing. *Proceedings of Tenth International Conference on Mobile Data Management: Systems, Services and Middleware*. 720-725.

He, T., Lin, J., Hu, Z., Zhang, J., Jia, W. and Su, J. (2014). BIM-Based Plan Modeling System at Preliminary Stage for Residential Real Estate Projects, *Proceedings of the International Conference on Computing in Civil and Building Engineering 2014*, 35(0): 488-495.

Langenhan, C., Weber, M., Liwicki, M., Petzold, F. and Dengel, A. (2013). Graph-based retrieval of building information models for supporting the early design stages, *Advanced Engineering Informatics*, 27(4): 413-426.

Lertlakkhanakul, J., Choi, J. W. and Kim, M. Y. (2014). Building data model and simulation platform for spatial interaction management in smart home, *Automation in Construction*, 17(8): 948-957.

Regateiro, F., Bento, J. and Dias, J. (2012). Floor plan design using block algebra and constraint satisfaction, *Advanced Engineering Informatics*, 26(2): 361-382.

Wang, L., Shen, W., N., Xie, H., Neelamkavil, J. and Pardasani, A. (2002). Collabrative conceptual design-state of the art and future trends, *Computer-Aided Design*, 24 (3), 34, 981-996.