Regularized Rebuild Workflow of HBIM for Built Heritage Documentation

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ABSTRACT:

Historic Building Information Modelling is a continuous process based on reverse engineering of built heritage. By reviewing the research on HBIM with the case study, this article analyzes the combination logic between different components, based on which designs an algorithm program for automatic model generation, and proposes a regularized rebuild workflow to realize the informatization and parameterized documentation of built heritage. This article proposes the parametric workflow based on Rhino + Grasshopper + Revit / OpenBuildings Designer, establishes the information index framework under the guidance of the HBIM model, and proposes the key technologies of informatization and parameterization of architectural heritage protection records. With reference to the point cloud, mapping map, survey photos, and documents, the regularized rebuild is carried out, and all the parameter nodes are visualized to facilitate error correction and modification. The framework of the regularized rebuild workflow is defined, and the problems of packet grouping principle, component combination mode, and output type are solved, and the algorithm principle is described in detail. According to the construction logic, the single building consists of six parts: tile roof, rafter, wooden carpentry, wall, decoration, and foundation. The work of investigation, modeling, and additional professional data are carried out by parts and items to create a "digital twin". This article solves the modeling problem of complex shape and node, and further improves the working method during the survey, and proposes to use an algorithm module to realize real-time association between professional data and model. Taking the grid system, wall brick, balustrade, tile roof, rafter as examples, through compiling and debugging in Grasshopper compiler environment, according to different input parameters, the program automatically outputs the corresponding model and contains professional data, which proves that the program is fast and accurate. The regularized rebuild workflow for HBIM by reference to point cloud is realized.

1. REVIEW

1.1 Concept of HBIM

HBIM is BIM technology applied for heritage documentation during the process of surveying, modeling, and information management. Its full name is Historic Building Information Modeling. It was first proposed by Murphy, an Irish surveying and mapping expert (Murphy et al., 2009), defined as a cross-platform program that creates parametric components by referencing the data acquired from point cloud or photogrammetry attaching historical data of built heritage to a parametric component library. In this context, HBIM means historic BIM. Accordingly, the workflow of HBIM contains on-site surveying, point cloud registration, parametric modeling, data attachment

This concept has been accepted gradually throughout the world, and in recent years HBIM has been topics of CIPA Symposium sessions and workshops, though many research papers in this field do not have to use the term. Figure 1 shows that almost a quarter of them use the term HBIM in their subjects, abstracts, or titles since 2008.
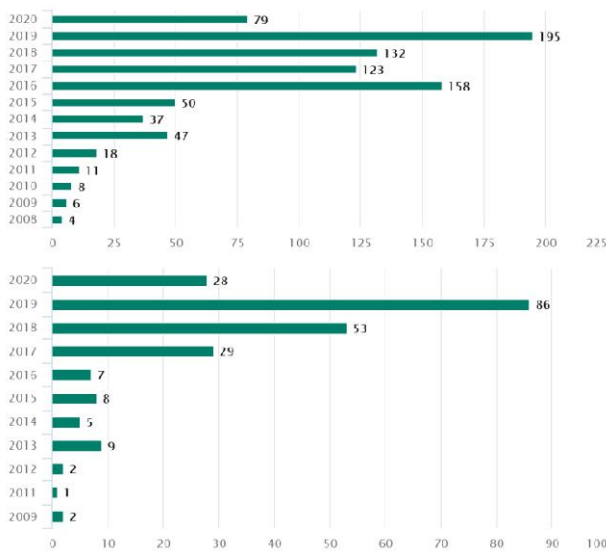

Figure 1. BIM and HBIM search records on EI
(https://www.engineeringvillage.com/search/expert.url?SEARCHID=e114088315404b659c87ca0e0a315c47&COUNT=1&usageOrigin=&usageZone=)

However, HBIM research around the world is mainly led by surveying professionals, while in China is mainly led by architecture professionals. Searching for HBIM topics on CNKI.net, the result shows that among 162 papers, only 7 were written in Chinese. The practice in China is mostly carried out using the term of heritage conservation and documentation based on BIM, rather than HBIM.

China issued *unified standard for building information modeling*, (MOHURD, 2016), in which BIM is defined as 'Building Information Model.'

It has been suggested that HBIM is a process of reverse engineering from disorder to order (WU et al., 2016), as an indexing framework, an ideal model, which based on the theory of typical survey and sample measurement and shows the specific forms, materials, constructions, and styles, without sticking to details such as ignorable tiny deformation or defects.

HAN Sai summarized the research and application directions of HBIM (HAN, 2017), including measurement and acquisition, modeling (including simulation analysis and 3D printing repair work using models containing only material and geometric information), and information management (application and expression).

It has been proposed that the main issue of HBIM is the balance between regularization modeling and differentiation modeling (Li et al., 2019), e.g. Table 1.

Table 1. Comparison of recording "differentiation" and "regularity" (Li et al., 2019)

	Recording Differentiation	Recording Regularity
Reference	Coordinates	Relationships (associative, constraint, and parametric)
Expression	Superficial phenomena	Intrinsic essence
Significance	With architectural semantic	Without architectural semantic included

The different professional background between the surveying discipline and the architecture discipline leads to different design motivation.

The modeling of HBIM is a process of reverse engineering, and there is no mature modeling standard for reference. Therefore, the modeling standard of HBIM can be determined according to the BIM delivery standard in the national standard.

The ministry of housing and urban-rural development of the people's Republic of China issued *unified standard for building information modeling* (MOHURD, 2016), *standard for design delivery of building information modeling* (MOHURD, 2018a), and *standard for graphic expression of building information modeling* (MOHURD, 2018b), *standard for storage of building information model* (MOHURD, 2019). There are three indexes as follows: Level of Model Definition (LOD1.0~4.0), Level of Geometric Detail (G1~4), and Level of Information Detail (N1~4).

It has been proposed that HBIM is a result of abstraction and simplification from the heritage (Bruno and Roncella, 2019), resulting in a difference between 'expressed model' and 'real object', in which the contradiction of regularization and differentiation is exist, unavailable of direct parametric modeling as in new-built design process.

1.2 Technical Routes of HBIM

The functions of the existing BIM software are more suitable for new buildings, and it is difficult to meet the three work phases of HBIM: surveying, modeling, and data managing. Grasshopper, as a graphical programming, and modeling platform for node visualization, now with its open source protocol, attracts many partners to publish various functional plug-ins on food4rhino[2], almost covering every profession. Asuni, the parent company of Rhino, has launched a BIM plug-in for Rhino: Visual ARQ, which can add professional data to the model in Grasshopper, and finally output IFC files, without bounding to BIM software.

HBIM projects usually use 3D laser scanning and digital photogrammetry for 3D data collection, supplemented by photography and other methods, to obtain and understand the architectural heritage geometric space data, color texture data, that is, the formation of the point cloud, mesh surface model, and other data, and then make real-world models and

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[2] https://www.food4rhino.com

orthophotos; at the same time, carry out on-site investigation and draft compilation, understand and comb the architectural space, color and texture data Structure, decoration and construction logic, shape characteristics. On this basis, the information model of architectural heritage is further created, and data information such as shape analysis, disease investigation, historical literature, engineering archives and value evaluation obtained through field investigation, literature research and follow-up interview are input to form data conforming to IFC Standard and other graphic data. After lightweight, it is converted to BIM data management and achievement delivery system, such as Autodesk BIM 360, Bentley ProjectWise; on this basis, through further development, it can be applied to various protection activities such as architectural heritage protection, research, management, exhibition and utilization, so as to provide efficient information services for heritage protection and utilization, e.g. Figure 2.
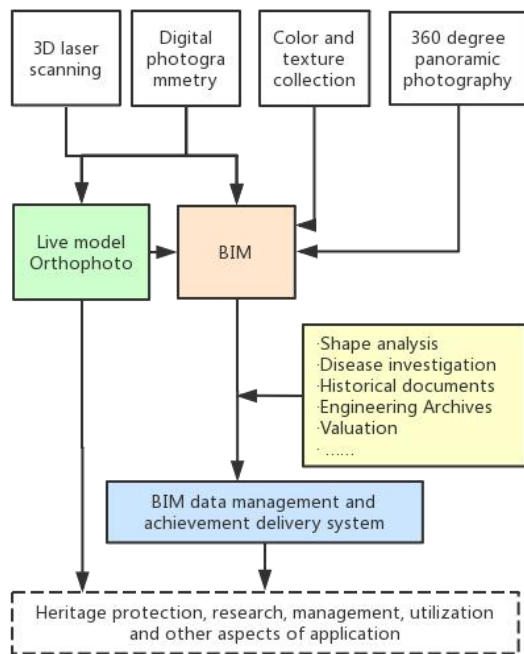
Figure 2. Technical route of HBIM proposed by the authors

1.3 Purpose and Significance

Aiming at the difficult problems often encountered in practice, this paper puts forward solutions and further summarizes the regularized rebuild workflow, which can complete HBIM more efficiently, modify at any time, generate model automatically, link the model and data in real-time.

2. PRACTICE OF REGULARIZED REBUILD

2.1 Rebuild of Grid System

The difficulty of grid system modeling lies in its irregular status. Grid is a prerequisite for all modeling work. It is impossible to get the correct grid directly through the survey, so we need to seek the optimal solution between the difference and regularity, so we need to use a genetic algorithm to rebuild the grid. This paper takes Jingfu palace as an example to show the regularized rebuild process.
Jingfu palace is a single-layer three-volume shed hall with 48 columns. The present situation of the column base is irregular distribution.
Import the point cloud in Rhino, refer to the point cloud, use the command of the fitting circle according to several points, draw

the contour line of the existing column base, and pick up the Grasshopper. Preset the orthogonal grid, set the angle and spacing of the grid as independent variables, set the expected target to 0, set the Gauss sum of the deviation value between the center of the rebuilt column base contour line and the center of the current column base contour line as the expected target value, and open the genetic algorithm solver, e.g. Figure 3.
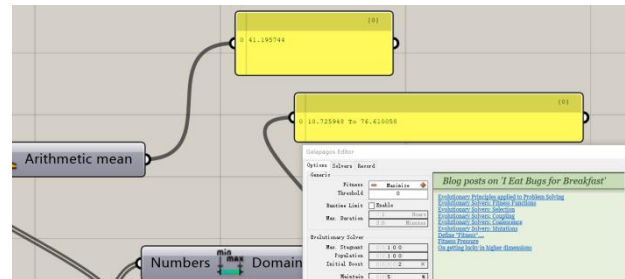

Figure 3. Genetic algorithm for optimal solution

After a few minutes, the average deviation of the center of the current and rebuilt column base is 41mm, which is distributed in the range of 10mm ~ 76mm. The direction of the green arrow is, the center of the current column base points to the center of the rebuilt column base, and the number is the deviation value, e.g. Figure 4.
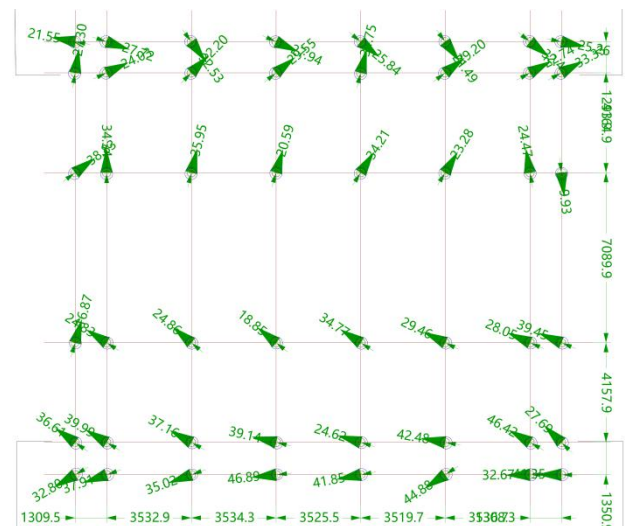

Figure 4. Deviation between the measurements and the results of rebuilding for the column feet

At this time, the red grid generated by the genetic algorithm is the rebuilt grid. Compared with the irregular plinth, the regular grid is more suitable for the next step of HBIM modeling. For example, if there is no orthogonal axis network in the big wooden beam frame, the modeling is completely in accordance with the current situation, all of them are crooked, which can not fully reflect the construction logic, and lose the significance of heritage protection through information record filing.

2.2 Rebuild of Wall Brick

Taking the wall bricks as the representative, similar large quantities of components, such as floor tiles, can be rebuilt and numbered automatically with the help of algorithms, which is convenient for further modeling and additional professional data. Take Jingfu palace as an example to show the rebuild process of wall bricks.

Firstly, the numbering rule is determined, and each brick is given a unique component ID. The location of the wall is determined by the partition number, and the location of each brick is determined by the numerical serial number. From the first brick in the lower-left corner of each wall to the last brick in the upper right corner, the rows and columns are distinguished by the two-digit serial numbers.

QT-2 ^ C ~ D-1-1 represents: Wall - on axis 2 - between axis C and D - first row - first brick.

QT-2 ^ C ~ D-1-9 represents: Wall - on axis 2 - between axis C and D - first row - ninth brick (last brick).

Because the brick wall is staggered masonry, so even rows to one more brick. Start with QT-2 ^ C ~ D-2-1, end with QT-2 ^ C ~ D-2-10, and so on.

Finally, according to the mapping rules, we can get rid of the number of the bricks outside the range of the wall, and then ensure the consistency of the list. At the same time, several colors can be selected for random coloring to form the appearance of different shades. The whole process is shown in Figure 5. All twelve walls of Jingfu palace rebuilt by the algorithm are shown in Figure 6.
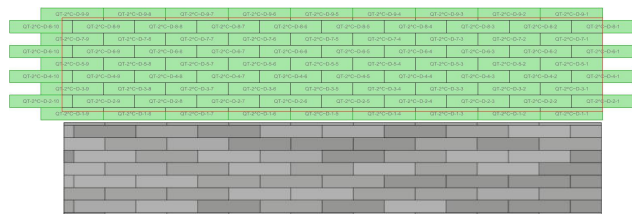
Figure 5. Regularized rebuild process of wall brick
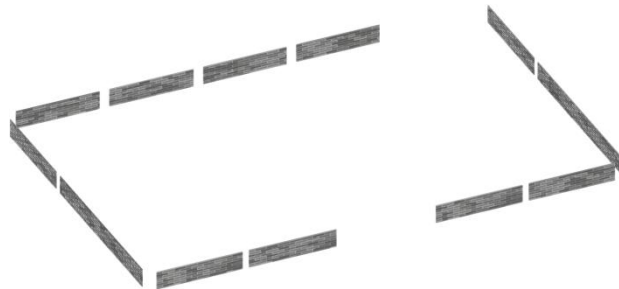
Figure 6. Rebuild of walls

In the future, the accuracy of modeling can be selected according to the survey accuracy and delivery standard. The rebuilt surface can be used to distinguish the bricks, and the solid with thickness can be used to represent the walls; the surface can also be directly extruded to solid, but the volume of the model will increase.

Likewise, other sub-models in two dimension could also be generated with auto-numbering, e.g. Figure 7, Figure 8.
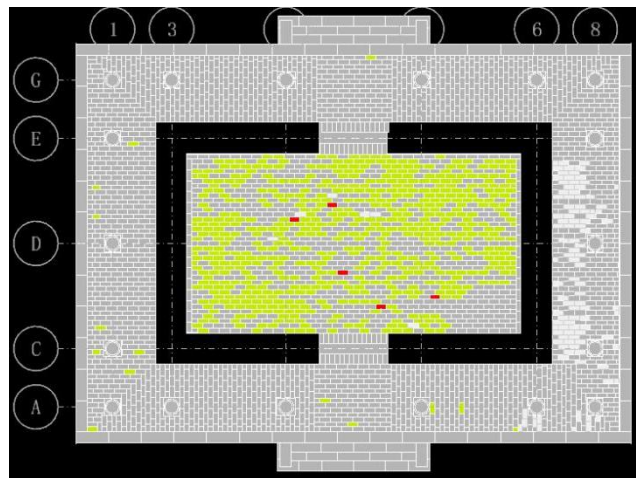
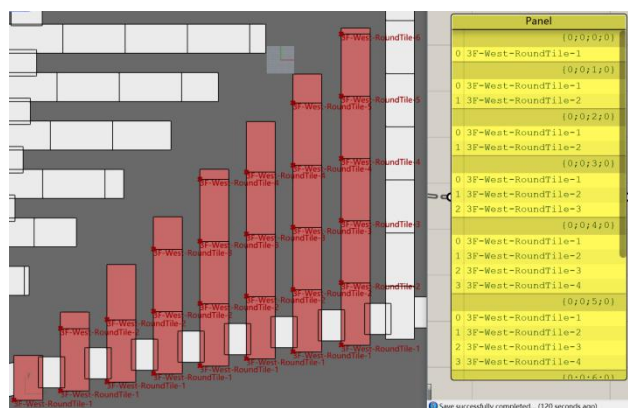

Figure 7. Floor bricks generated with auto-numbering

Figure 8. Roof tiles generated with auto-numbering

2.3 Rebuild of Balustrade

The balustrade can be regarded as a linear component around the outline of the platform foundation, and it also contains several different components, such as the column head, drum-shaped bearing stone, bottle-shaped bearing stone and so on. Taking the Great Buddha Hall of Zhangye Great Buddha Temple as an example to show the rebuild process of the balustrade.

Firstly, according to the point cloud and the drawing, the contour line of the platform base and the different components are determined, e.g. Figure 9. Then, the reference point, reference line, difference component and so on are picked up to the dependent variable input end of the algorithm generator, and the parameters of the independent variable input end are adjusted, e.g. Figure 10. The final result is shown in Figure 11.
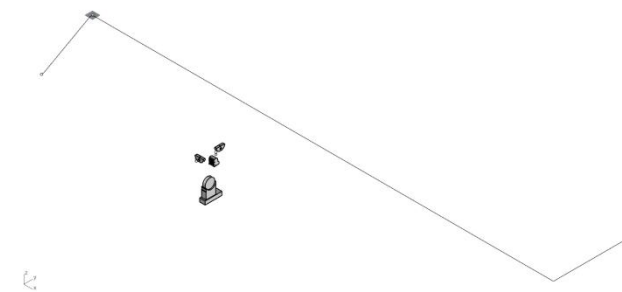

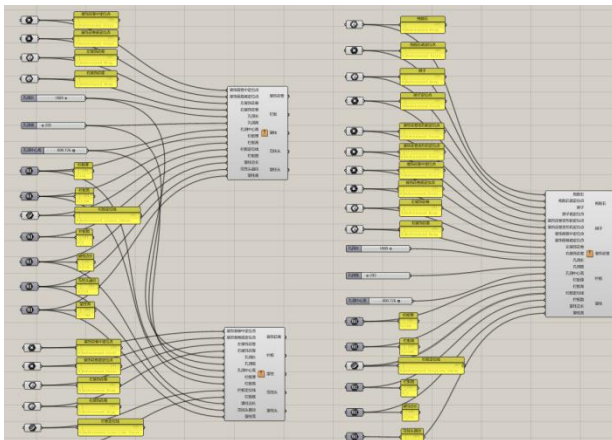Figure 9. Balustrade path and irregular components

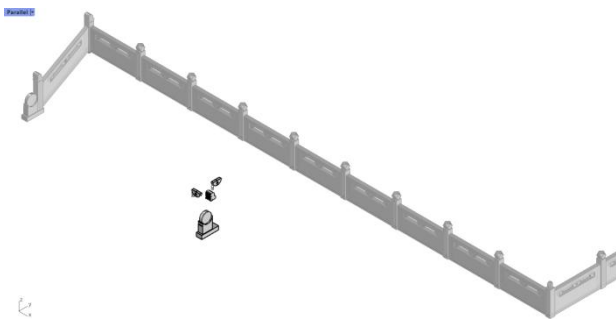Figure 10. The generator of Stone Balustrades

Figure 11. Generated Stone Balustrades

When it is necessary to improve the accuracy of geometric details, the referenced differential components can be directly modified, and the generated model will be updated automatically. The details are shown in Figure 12.
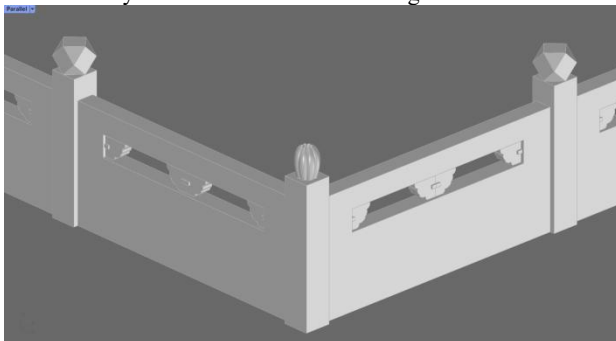

Figure 12. Details of Stone Balustrades

2.4 Rebuild of Tile Roof

The difficulty of tile roof modeling lies in its complex surface shape and a large number of repetitive components. Taking Wenchang Pavilion in Jiayuguan Pass as an example to show the rebuild process of tile-roof.

Wenchang Pavilion in Jiayuguan Pass is a two-level Nine Ridge Roof Pavilion. The building components of tile-roof can be classified into four types: tile, roof ridge, ridge ornament, and brick wall. Ridge ornament and brick wall are differential components, which do not contain certain rules and are not suitable for regularized rebuild. Direct modeling method can be used to model them separately. Tile and roof are regular components, which are suitable for extracting rules for regularized rebuild.

Import the point cloud in rhino, and use the interpolation point curve to draw the contour of the key parts, e.g. Figure 13.
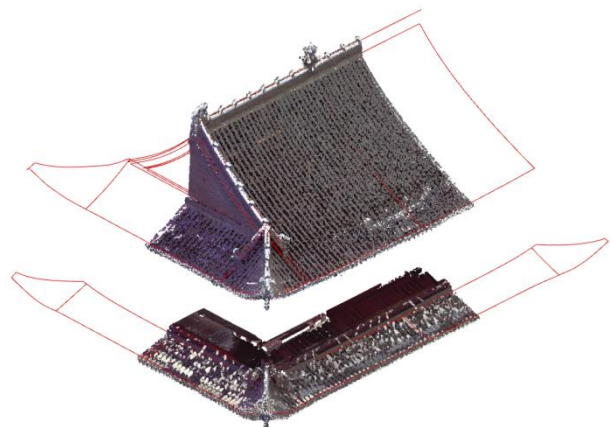

Figure 13. Extracting skeleton curves with referenced point cloud

Pick the profile curves to Grasshopper, connect to the input of algorithm generator, and adjust other inputting parameters, e.g. Figure 14.
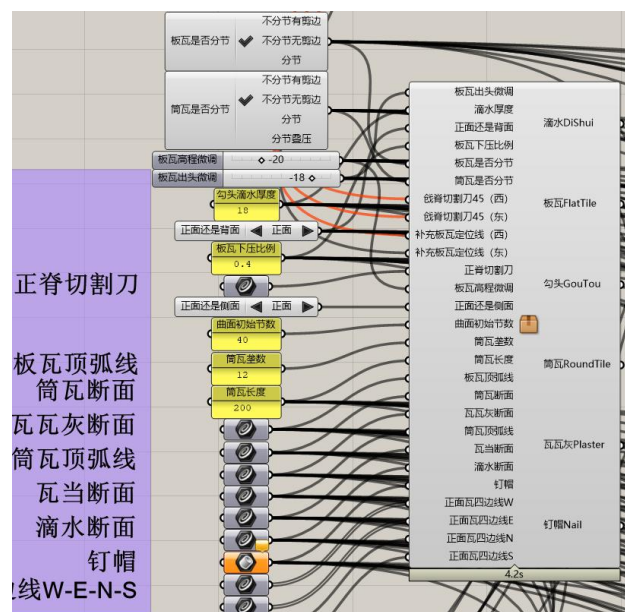

Figure 14. The binary cluster (generators) of roof tiles

After 4.2 seconds, the tiles on the wing corner of the front slope are automatically generated. Similarly, ridges can be generated automatically. According to the delivery requirements, different geometric details can be selected, such as modifying the "segmented or not segmented" parameter, each tile or ridge with real size can be obtained, e.g. Figure 15, Figure 16.
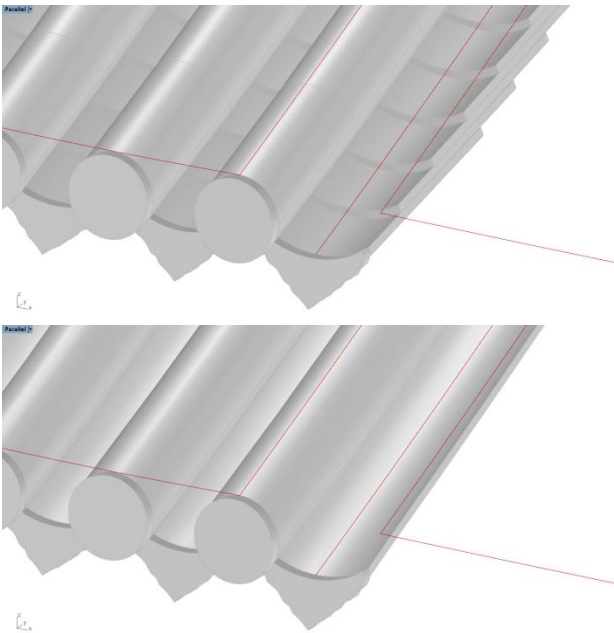
Figure 18. "Butterfly" tiles

Figure 15. Comparison of different levels of geometry details
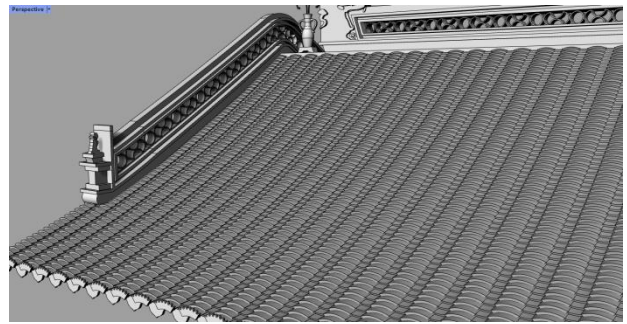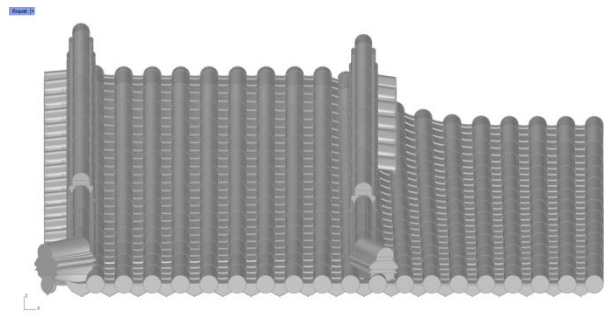

Figure 19. Cascade round-ridge roof

2.5 Rebuild of Rafters and Accessories

The difficulty of rafter-roof modeling lies in the complex surface shape and a large number of repetitive components. Taking Wenchang Pavilion of Jiayuguan Pass as an example to show the process of regularized rebuild.

Wenchang Pavilion in Jiayuguan Pass is a two-level Nine Ridge Roof Pavilion. The building components of rafter-roof can be classified into four types: rafter, roof board, eave, and corner beam. The corner beam belongs to the irregular component, does not contain certain rules, is not suitable for the regularized rebuild, may use the direct modeling method to model separately. Rafter, roof board, and eave are regular components, which are suitable for extracting rules for regularized rebuild.

Import the point cloud in Rhino, and use the interpolate curve to draw the skeletons of the key parts, including the skeleton of the bottom rafter head, the skeleton of the flying rafter head, and the skeleton of the bottom rafter tail, e.g. Figure 20.

Figure 16. Generated roof

Roof tiles generator also supports other forms of roofs, which can be automatically generated by modifying the corresponding input, such as round-ridge roof with gutter (Figure 17), butterfly tiles (Figure 18), and round-ridge roof with turning (Figure 19).
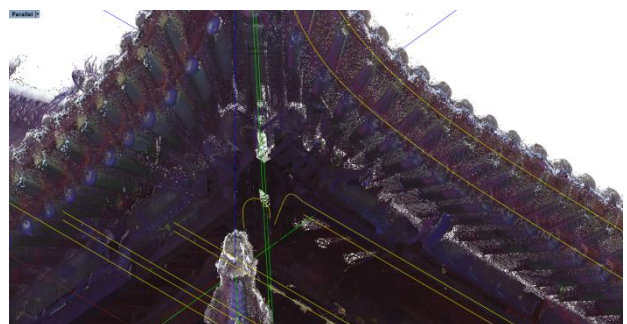

Figure 20. Extracting the skeleton curves by reference to point cloud

Pick the skeleton curves to Grasshopper, connect to the input of algorithm generator, and adjust other inputting parameters, e.g. Figure 21.
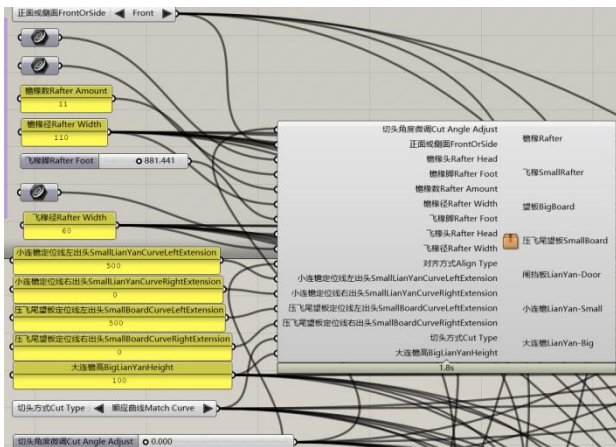

Figure 17. Round-ridge roof (*juanpeng*) with a gutter

Figure 21. The binary cluster (generators) of rafters and accessories
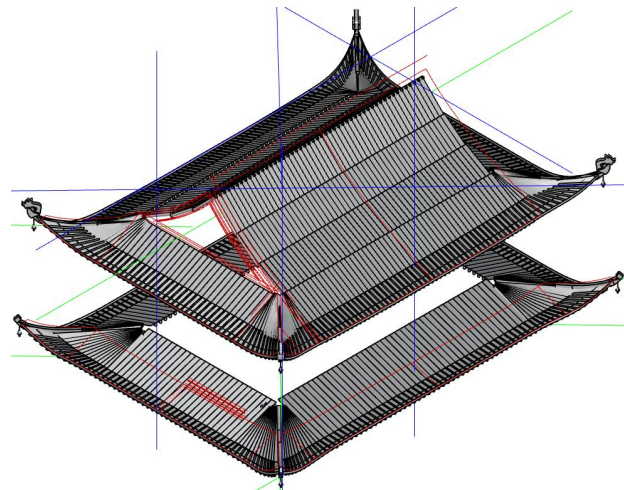
After 1.8 seconds, all of the rafters, roof boards, and eaves of the front slope are automatically generated. The parameters can also be adjusted directly to choose whether to cut the "flying" rafter head or not, and the side of the "flying" rafter is perpendicular to the roof board (method of Hexi area in northwest China) or the ground (method of Beijing area) to generate different "flying" rafters, e.g. Figure 22, Figure 23. And the HBIM of Jiayuguan Pass presented in Navisworks well illustrated the practice of regularized rebuild, e.g. Figure 24.
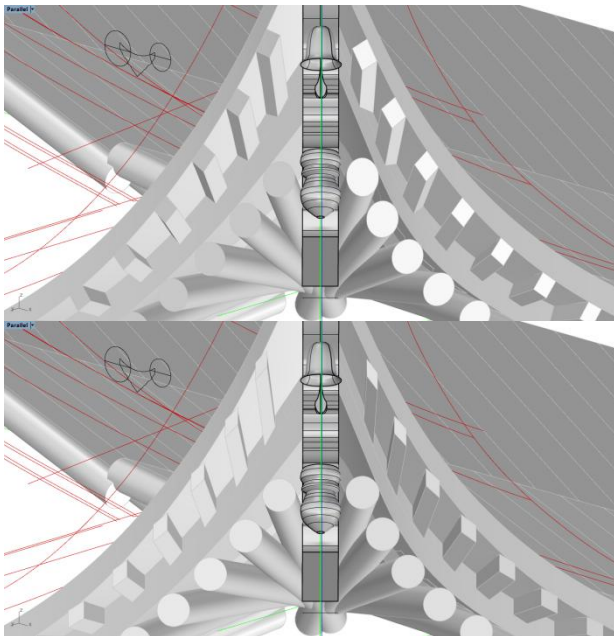

Figure 22. Comparison of different methods of "flying" rafters
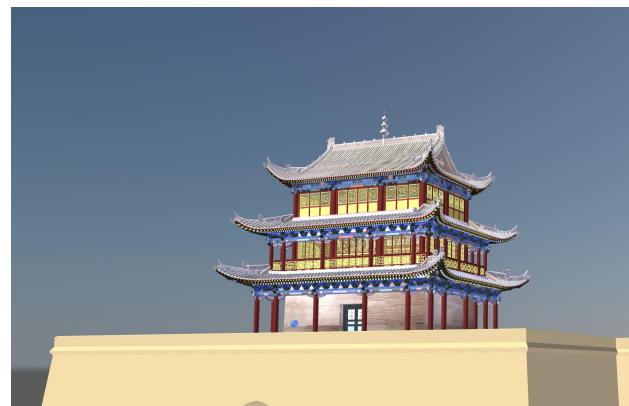

Figure 23. Rafters and accessories

Figure 24. Presentation HBIM model in Navisworks

3. WORKFLOW OF REGULARIZED REBUILD

By reviewing the above several typical cases, we can develop several algorithm modules, combining metadata such as component size and combination logic of architectural heritage, achieving a regularized rebuild algorithm system. We can select the appropriate algorithm modules for heritage ontology, automatically complete the information modeling, and retain all process data, which can be consulted and adjusted at any time to form a whole set of knowledge graphs of heritage.

The workflow of regularized rebuild includes the following three stages, e.g. Figure 25.
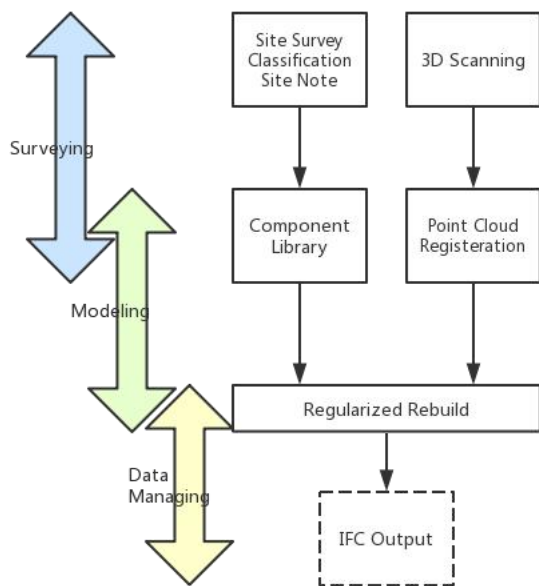
Figure 25. Workflow of Regularized Rebuild

Applying BIM technology to digital documentation of architectural heritage is HBIM. Based on the existing heritage, HBIM is reverse engineering that does not need to cooperate with other specialties (structure, water, heating, electricity), such as collision detection, schedule arrangement, etc. BIM software is not equal to BIM. For example, PetroBim (Agustín and Quintilla, 2019) online platform has no modeling function and can still complete digital records to a certain extent. Therefore, it can be regarded as HBIM if it can complete the digital documentation of heritage (such as modeling and associating historical information) and deliver (not limited to the existing software and format). In Rhino, we can not only build differentiated models, but also regularized models (through Grasshopper visual programming). We can complete the identity assignment of class, family, type and material, and output IFC file directly (need to install VisualARQ plug-in). Then Rhino can be used as the software platform of HBIM to solve problems in one stop. Furthermore, it can also achieve two-way linkage, import and export excel tables, link files, manage photos, and realize information closed-loop.

This paper reviews the related research of HBIM, and proposes the technical solution of algorithm reconstruction for the typical problems in practice. By using Rhino, Grasshopper, and VisualARQ, the algorithm rebuild of regular large quantities of components can be completed efficiently in Rhino. However, the traditional way of work is limited by BIM software, which can only realize the parametric expression of components, but can not complete the automatic assembly according to the logical relationship between components, and can not automatically complete the update of all professional data after model modification. It is convenient to deliver the final results that fitting national standard. Then, it puts forward the related standards of regularized rebuild workflow, covering the whole cycle of HBIM work, realizing the process from point cloud to IFC in one step, building the "digital twin" of architectural heritage, laying the foundation for the further development of online comprehensive management and achievement delivery system in the future, which can be viewed and managed on the website in line with the IFC Standard (i.e. in line with the national standard).

REFERENCES

Agustín, L. and Quintilla, M., 2019. VIRTUAL RECONSTRUCTION IN BIM TECHNOLOGY AND DIGITAL INVENTORIES OF HERITAGE. ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-2/W15: 25-31.doi:10.5194/isprs-archives-XLII-2-W15-25-2019

Bruno, N. and Roncella, R., 2019. HBIM for Conservation: A New Proposal for Information Modeling. Remote Sensing, 11: 1751.doi:10.3390/rs11151751

HAN, S., 2017. Information Management and Presentation of Architectural Heritage Based on HBIM: Taking Three Duty Rooms in Forbidden City as an Example, Tianjin University

Li, D., Wang, X., Bai, C. and Wu, C., 2019. DISCUSSION ON THE PROBLEM OF REGULARIZED RECONSTRUCTION IN HBIM. ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-2/W15: 657-662.doi:10.5194/isprs-archives-XLII-2-W15-657-2019

MOHURD, 2016. unified standard for building information modeling, GBT 51212-2016

MOHURD, 2018a. standard for design delivery of building information modeling, GBT 51301-2018

MOHURD, 2018b. standard for graphic expression of building information modeling, JGJT 448-2018

MOHURD, 2019. standard for storage of building information model

Murphy, M., McGovern, E. and Pavia, S., 2009. Historic building information modelling (HBIM). Structural Survey, 27(4): 311-327.doi:10.1108/02630800910985108

WU, C., LI, K., LI, S. and ZHANG, L., 2016. From digitization to informatization: the application of information technology in the field of Architectural Heritage. China Cultural Heritage(02): 18-24