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A BIM Inspired Supporting Platform for Architectural Design

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ABSTRACT

In conventional design processes, various kinds of design analysis made by professional consultants often arrive too late to assist architects to make strategic decisions at early design stages. The analysis is thus merely used for presentation in such cases.

This paper proposes that a design “dashboard” should be integrated into modeling tools used by architects at early design stages. This dashboard should provide visual presentation for information regarding estimated construction cost, structural analysis, and building performance in real time. It is shown that in a generative modeling platform, interfaces can be developed to connect tools for modeling and design analysis, so that the mentioned characteristics of design dashboard can be implemented and customized for specific design cases.

To illustrate the viewpoints, this paper presents an actual design case of an apartment building to show how the design dashboard assists the architect with prompt information on daylighting analysis at early design stages. In the case, Monte Carlo simulation is used as the basic method for prompt analysis with merely the information regarding building mass.

Keywords: LOD100, dashboard, early stage of architectural design, strategic decision.

1. INTRODUCTION

Conventional architectural design decision-making procedures have long followed this scenario: The architects hand over a design model to other professional consultants; after the consultants have analyzed the model, they provide feedback concerning the results of analysis to the architects, who then revise the design based on the feedback, so that the design will better comply with the proposed requirements in the architectural plan. In this process, the architects must first provide a basically complete and relatively precise model to the consultants. Without the sufficient information provided by this relatively-complete design model, the consultants cannot subject the model to analysis, and cannot obtain precise results. Although analysis of modeling results can objectivity reflect the architects' design results at certain levels, its ability to give correct decision-making information to architects involved in the design process is limited. When the feedback provided by consultants cannot satisfy the requirements of the architectural plan, architects face the following two alternatives if they wish to preserve design quality:

1. They can either perform large-scale revision of the design based on the assessment data in the feedback, and thereby simultaneously satisfy price, physical environment, and structural requirements;
2. Or they can only attempt to satisfy one requirement, such as by meeting structural and physical environment requirements, while sacrificing budgetary requirements.

But while the first alternative will increase design cost, waste time, and reduce efficiency, the second alternative cannot meet all the goals of the architectural plan. It is clearly apparent that, during the early design stage, consultants' assessments provide little timely assistance to architects who must make correct decisions, and instead chief constitute a format of presenting information.

In recent years, increasingly widespread use has been made of building information modeling (BIM). Compared with traditional modeling tools that are reliant on paper methods, BIM can be used to generate 3D models, and can only incorporate plentiful information in these models. This information can

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be effectively applied to design, structural planning, construction, management, and even operation and maintenance following completion [8]. The emergence of BIM has greatly enhanced the level of information processing technology in architecture, and BIM help architects obtain and control design information in the design process by facilitating the exchange of design information. These improvements can provide opportunities to ease the quandary mentioned above.

We usually refer to modeling during the early design stage as LOD100. According to American Institute of Architects (AIA) document E202, "The level(s) of Development (LOD) describes the level of completeness to which a Model Element is developed. [1]" The LOD modeling includes five stages, namely the conceptual, approximate geometry, precise geometry, fabrication, and as-built stages [6]. Of these stages, the AIA defines LOD100—the conceptual stage of BIM modeling—as follows: "Essentially the equivalent of conceptual design, the model consists of overall building massing. And the downstream users are authorized to perform the whole building types of analysis (volume, building orientation, cost per square foot, etc.). [1]" In the case of most experienced architects, the types of information mentioned in this definition are simple and easy to acquire. In other words, even without assistance from a BIM model, during the early stage of the conventional design process, an architect can still easily obtain the foregoing information and employ it in architectural decisions. Because of this, due to the influence of conventional design concepts, many people have questioned whether the lack of information contained in the LOD100 makes it necessary to perform modeling.

Nevertheless, during the design process, the most important design decisions are usually made by the architect during the early design stage [10]. And according Duffy et al., 80% of costs are decided during the early design stage [7]. Furthermore, Chong noted that even the application of the highest standards during the detailed design stage cannot make up for losses due to erroneous decisions during the early design stage [3]. As a consequence, the early design stage will have a direct influence on the subsequent design, and will therefore affect design quality. This underscores the importance of LOD100 modeling.

Moreover, interviews with architects revealed that, apart from functional layout and aesthetic/creative aspects, architects must consider three key pieces of design information during the early design stage: budget, physical environment, and building regulation review. An LOD100 model should therefore include the following basic design information corresponding to these three aspects, as shown in Tab.1.

In contrast with the information contained in an LOD100 model as defined by the AIA, the information in Tab. 1 is considerably more specific and detailed, and reflects the aspects that architects must consider to a greater degree. In other words, although an LOD100 model may be lacking in information, when subjected to certain types of analysis, even such an information-deficient model can yield certain valuable information through further analysis, and this information may include items that had been neglected by the architects as they focus their attention on certain aspects at the expense of others. For instance, this information may include the effect of control of building massing on lighting and ventilation. This type of situation occurs especially often during the early design stage, which can be attributed to the fact that architects tend to diverge their concept widely during the early design stage. Furthermore, when architects must choose from among various proposals, they must assess and revise each proposed model. This kind of assessment and revision must typically be performed many times, and some information is invariably neglected during this process. From another angle, as the architectural form grows increasingly complex, architects find it increasingly difficult to rely entirely on their own personal experience to make judgments during the assessment process. As a result, architects cannot wholly consider information derived from the complex form. This implies that architects will inevitably neglect certain items of information while making design decisions, which will affect design quality.

Based on these considerations, architects need a "dashboard" that can intuitively and quantitatively display the foregoing information to help them make decisions during the early design stage, which will ensure that feedback from consultants is not merely

Aspect	*Information*
Physical	• Building massing Geometry form (natural ventilation of major interior spaces of building) Construction type General functional layout • Envelope of building Orientation of facades Construction type of envelope Window percentage • Surrounding buildings Planting Landform
Estimate	Building massing Structural type Construction type of envelope Total construction area
Building regulation review	Planning layout Building massing Building Coverage Ratio Greening Rate

Tab. 1: Information which an LOD 100 model should contain [2].

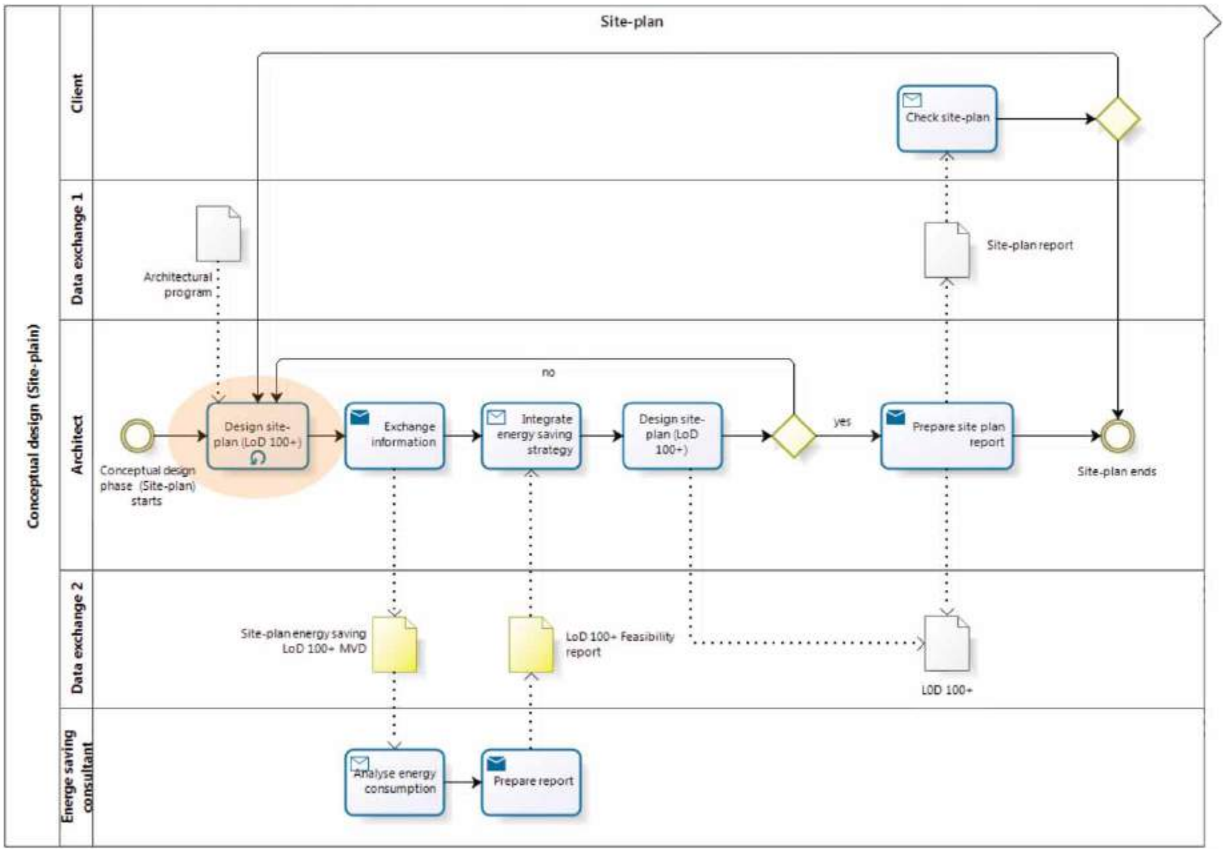

Fig. 1: BPMN of the conceptual design and site planning stage: Example of an energy-conserving design.

the presentation of results. This kind of dashboard should serve architects in the same way that an aircraft's instrument panel allows a pilot consult data at take-off and ensure the success of the mission.

2. MAIN IDEA

This study chiefly proposes the use of a "dashboard" employing generative modeling technology in the early design stage of architectural projects employing BIM design process in order to help architects make correct decisions.

2.1. BPMN and Early Architectural Design Stage Processes

BPMN (Business Process Modeling Notation) provides clear ways to describe activities and the information flows between activities in what is called a Process Map [8]. Taking an energy-conserving design during the conceptual site planning stage as an example, we can see from Fig. 1 that the architect performs design on the basis of architectural planning documents, and hand over a site energy-conserving design to an energy-conservation consultant. The consultant then performs assessment and sends a feasibility report back to the architect. The feasibility report includes energy conservation design principles, which helps the architect to perform design during the subsequent stage in accordance with these technical design principles. After achieving energy conservation design objectives, the architect submits a site plan to the project owner for approval, and must revise the site plan if the submitted plan is not approved, forming a cycle. This cycle involves communication between the architect and other consultants.

A smaller work cycle exists within this cycle (the oval highlighted portion of Fig. 1), and chiefly involves communication between architects to themselves. An architect can perform modeling of his or her own design program on the Rhinoceros/Grasshopper platform, and can use add-ons linked with Grasshopper, such as Ecotect and Karamba, to perform analysis and assessment of energy, structural, cost, and regulation aspects. Of course, architects can use different tools to perform analysis and assessment depending on the focal points of different design cases. After performing analysis and assessment, the resulting information can be fed back to architects via the dashboard. In accordance with assessment information fed back in real-time, the architects can make decisions concerning the model, or revise it, forming a cycle (Fig. 2.). As described above, via this cycle, architects may assess and revise many different concepts with great frequency during the early architectural design stage, and large amounts of information may be exchanged. As a consequence, there is a close relationship between design and modeling. Nevertheless, conventional modeling cannot meet the need for the repeated real-time feedback of information during the model assessment process. It can be seen that a dashboard employing generative modeling technology as a platform can play a vital role by presenting feedback information to architects in real-time.

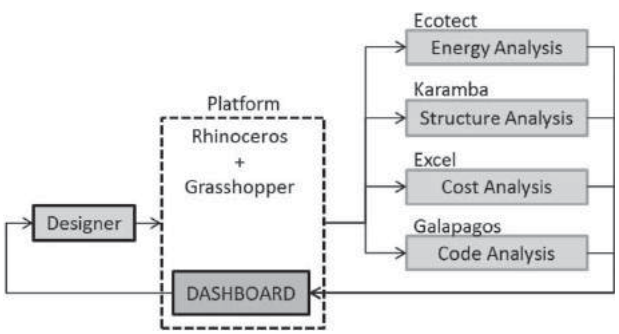

Fig. 2: Work cycle during the early architectural design stage.

2.2. Generative Modeling

As mentioned above, design and modeling have a very close relationship, and involve the exchange of large amounts of information. This exchange of information can proceed even more smoothly with help from generative modeling: design and modeling are performed at the same time, design decisions will directly become procedural information and serve as the main subject of the information model. This is because generative modeling is a technology that is based on an entirely different concept from ordinary computer drawing and modeling. The key feature of generative modeling is that it takes procedural information as its main subject, and relies on computer interpretation and processing to derive drawings and models. When generative modeling is used, architects do not need to pay any data processing price in the design revision process. Another notable feature of generative modeling is that it can express complex geometric forms using minimal data, and can also integrate specialized information in the modeling process, ensuring that subsequent manipulations and adjustments will not affect earlier decisions [12]. Architects can revise a design anytime during the design process, and the model will be updated accordingly in real-time. In these circumstances, design and modeling are closely-connected two-way operations. Integration through generative modeling can lower model editing costs, while greatly enhancing the efficiency of information transfer between design and modeling.

In light of these two features, generative modeling is very suitable as a language of communication between different specializations. In addition, it can also enable architects to manipulate architectural forms while simultaneously controlling the presentation of architectural information during the creative process [11]. A generative modeling platform constructed from Rhinoceros/Grasshopper can meet the need for these functions. We therefore believe that Rhinoceros/Grasshopper is a suitable platform for a dashboard.

2.3. Dashboard

The study team used generative modeling to establish a dashboard that could express the three aspects of the physical environment, budget, and building regulation review during the early architectural design stage. As shown in Fig. 3, the dashboard is a means of quantitatively expressing the relationship between orientation of building massing and heat gain/loss. The architects' concept of massing at the early design stage will consist of not only of geometric information, but also include different massing orientations and heat gain/loss. And of course the form and construction of the walls in different orientations will involve budgetary factors. For instance, glass curtain walls meeting lighting needs may increase costs, while the use of ordinary concrete walls may cut costs and meet the need for reduced energy consumption. This is obviously an instance of trade-off decision-making. These many complex factors inevitably influence architects' decisions during the early design stage. The dashboard can use generative modeling to link a very simple massing model with energy conservation calculation software, can very intuitively express the heat loss or gain resulting from different building massing orientations and different construction methods during the early design stage, and can express results in quantitative form. For instance, the dashboard can express the result of the use of a double skin in certain areas or walls with a specific window ratio. When expressed via a dashboard, data concerning these aspects will enable architects to make early design stage decisions in a more intuitive and rational manner. As shown in Fig. 4., a dashboard allows investigation of the trade-offs between structural form and cost. In this case, we use a genetic algorithm to calculate the relationship between structural bearing ability and minimizing the use of steel in a structural mass (which implies minimization of cost) in order to obtain an optimal structural form, and also use the dashboard to express the results of stress analysis for the structure. A dashboard can thus provide quantitative and intuitive assistance to architects designing a structural during the early design stage. Fig. 5.shows a building regulation review dashboard established using generative modeling. In this dashboard, architects can clearly see compliance

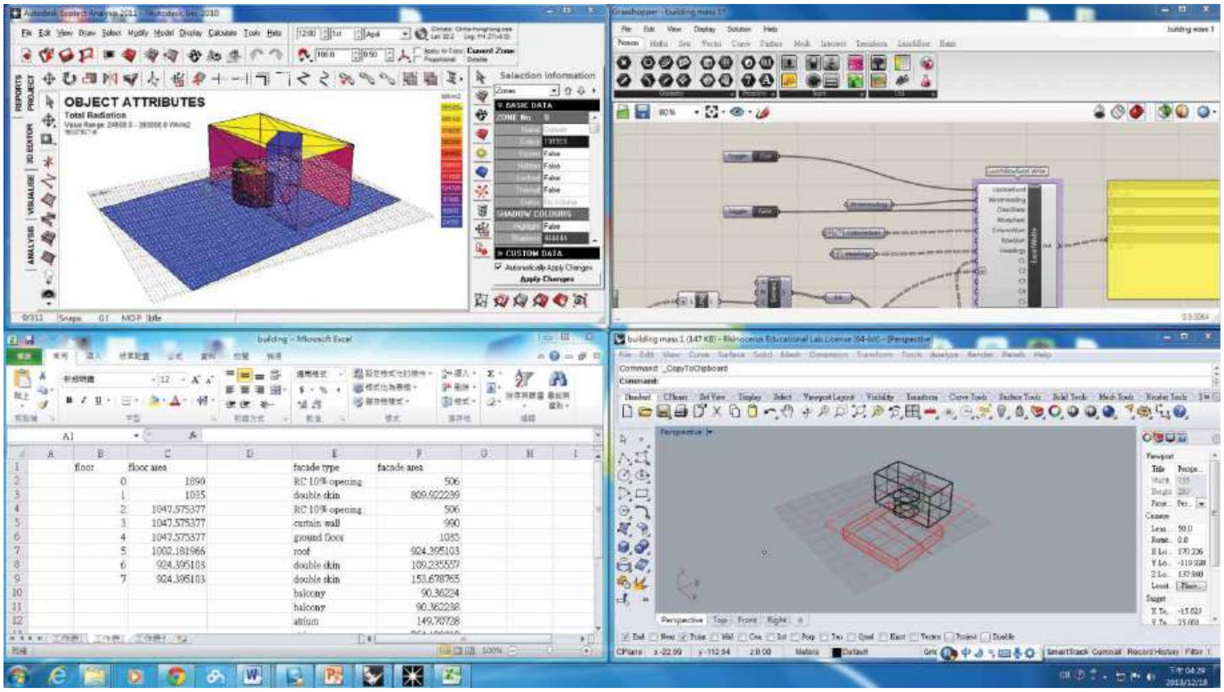

Fig. 3: A quantitative presentation of the relationship between the orientation of building massing and heat gains and loss by dashboard.

with local laws and regulations, and differently colored portions represent permissible building massing size calculated on the basis of shadow limit regulations corresponding to different roads.

It can be seen that the dashboard can effectively present the information included in the LOD100 model in an intuitive manner. It is also worth noting that the dashboard must comply with the following requirements:

- To ensure that architects do not make subjective judgments based on their limited personal experience, the dashboard must provide architects with quantitative, highly visual, and high intuitively feedback information.
- In fact, architects do not need and cannot obtain precise feedback information during the early design stage. A dashboard therefore needs only to present estimated information.
- When many proposals have been thrown out during the early design stage, a dashboard can promptly provide design feedback information to architects, facilitating their decision-making.

To provide an even better explanation of the dashboard's three features, in the following section this study uses physical environment information—one of the types of information included in the LOD100 model, to explain how architects can examine the effect of building massing design during the early design stage on lighting and the plan's functional layout during later design stages, and thereby prove that valuable information helping architects to make correct decisions can be obtained from simple building massing by analysis during the early design stage.

2.4. Monte Carlo method

We use the Monte Carlo method to explore the issue building lighting. The Monte Carlo method is an extremely important method of calculating numerical values, and employs probabilistic statistics theory. Assuming we want to calculate the area of an irregular shape, the complexity of calculations will be in direct proportion to the irregularity of the shape. The Monte Carlo method is based on the following thinking: Assuming that you have a bag of beans; scatter the beans randomly within a certain defined extent containing a shape, and then count the number of beans within the shape. The number of beans within the shape as a proportion of the total number of beans will be the area of the shape to the total specified area. The more beans that are scattered, the more precise the result is. Accordingly, a computer program can be used to generate large amounts of randomly-distributed coordinates, and the number of points within the shape counted; the number of points within the shape as a proportion of the total number of points and the area in which the coordinate points are located can then be used to calculate the area of the shape [9]. The Monte Carlo method is used in this example chiefly because architects do not need extremely precise lighting feedback data during the early design stage; they only need to understand

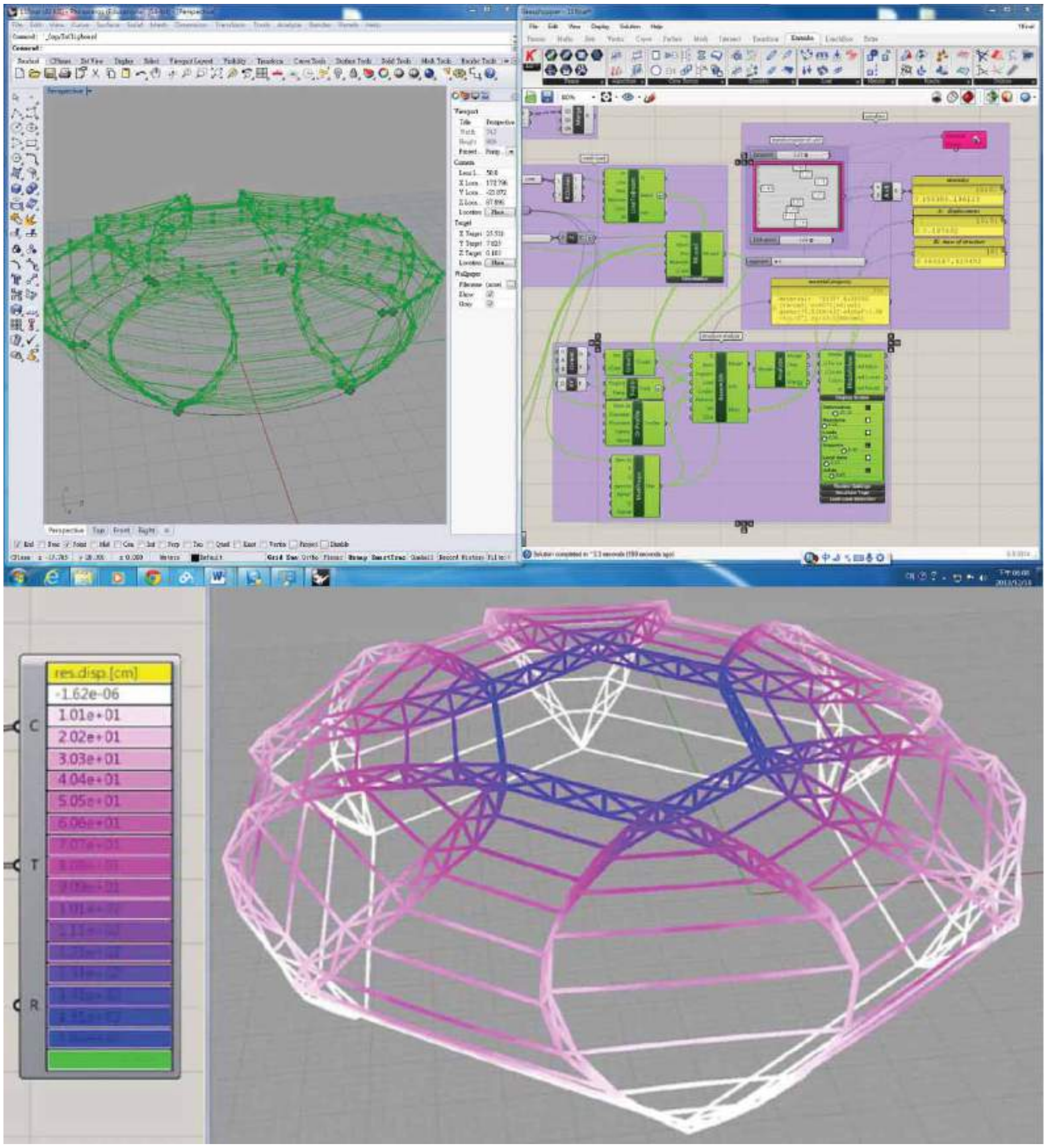

Fig. 4: The quantitative and intuitive presentation of structural form and cost by dashboard.

the general effect of the massing they have designed on the lighting. This will ensure that bias in architects' strategic design decisions will not lead to increased design cost at a later stage.

3. CASE STUDY

This study takes a bachelor apartment building design case located in the Chinese city of Xiamen as an explanatory example. This project in Xiamen's Houpu development area is located in the city's Huli District, and will be mostly situated on two irregularly-shaped parcels (A & B) with a north-south relationship. The project will chiefly consist of commercial space on the lower floors and bachelor apartments on the upper floors. A residential district is located on the northeast side of the site. In order to meet sunlight distance requirements between the apartments on parcel A and the residential district on the northeast side, and provide a set-back from the open space on the northern side of parcel B, the architects had to locate the apartment building toward the southern side of parcel B as much as possible, resulting in a roughly triangular massing, as shown in Fig. 6.. This study entered the LOD100 massing model of the apartment building on parcel B into Rhino, and performed programming in Grasshopper to use the Monte Carlo method to analyze the layout of the massing, proving that the dashboard can help apartments perform decision-making during the early design stage. Analysis was performed targeting two main aspects:

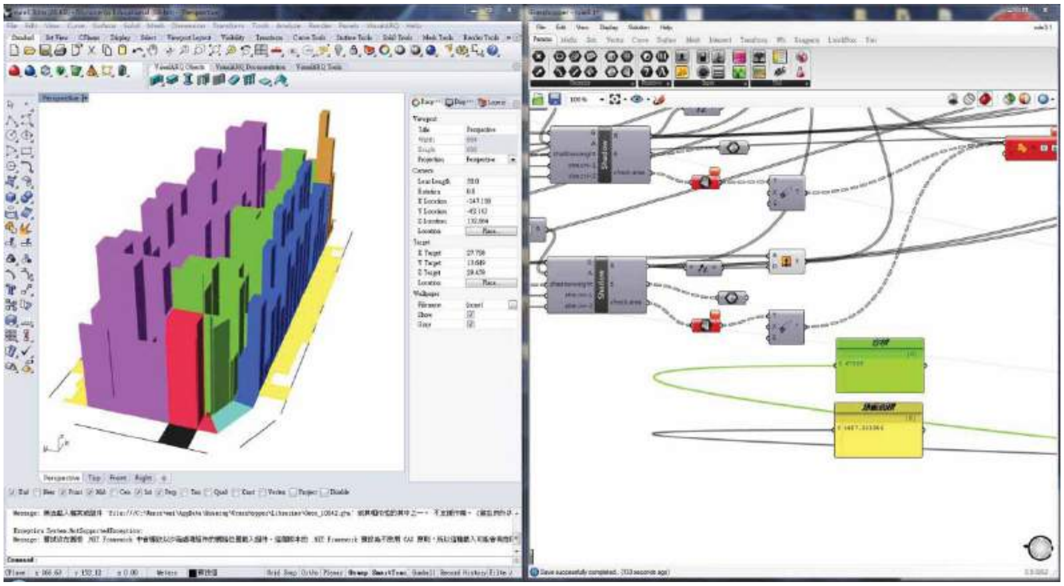

Fig. 5: An intuitive presentation of regulation recheck by dashboard.

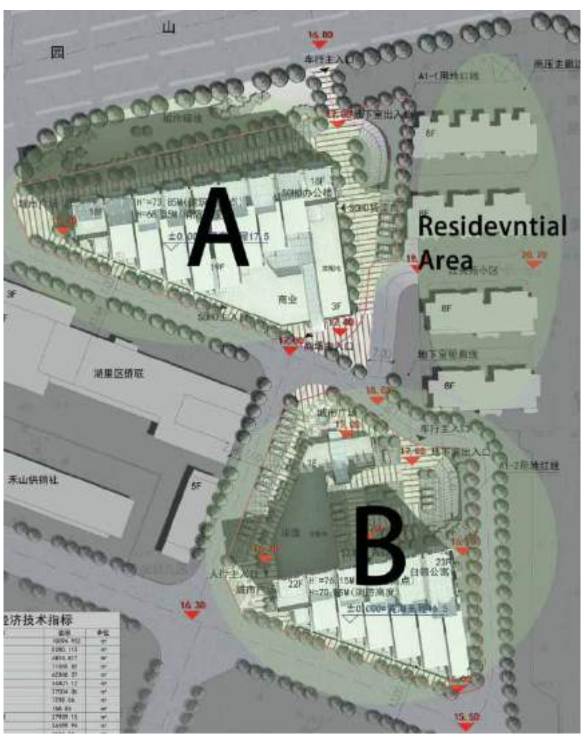

Fig. 6: General plan.

3.1. Influence of Lighting and Adjustment of Massing on the Internal Functional Layout

Because the apartment units must have natural lighting, the apartment unit space (not including horizontal public transport, corridors, and other public equipment spaces) must have a depth of less than or equal to 10 m. This implies that if we use the Monte Carlo method to randomly assign points within the building plan, those points within 10 m of the external outline of the building will be within the range of effective lighting, while those points further than 10 m from the outline will not have effective lighting. Here the value of 10 m was obtained from interviews with the architects. In proposal A, points randomly generated using the Monte Carlo method within the 10 m scope of effective lighting comprised 86% of all points. This implied that 86% of the area on each floor of the massing designed by the architects could be used for apartment units. This information was able to help the architects judge whether a sufficient area was available for effective use in the apartment units. The architects could then lay out the apartment units so that they had access to effective lighting, and use the interior areas with insufficient lighting as spaces with low lighting requirements, such as public transport areas and corridors (see Fig. 7.):

In fact, the architects must make continuous adjustments to building massing during the design process. For instance, from the start, the architects had to consider the influence of changes in the overall massing size on the subsequent internal functional layout, which might result in the apartment units being unable to satisfy lighting requirements if their depth is too great. On the other hand, too small a massing might make it impossible to satisfy the building area requirements of the architectural plan. It can be seen from Fig. 8 that proposal B increases massing by a factor of 1.2 compared with proposal A. When the effective lighting distance was set as less than or equal to 10 m, only 77% of the points were located within the scope of effective lighting, indicating that the area with poor lighting had risen to 23% of the building area. This was probably an unacceptably large area

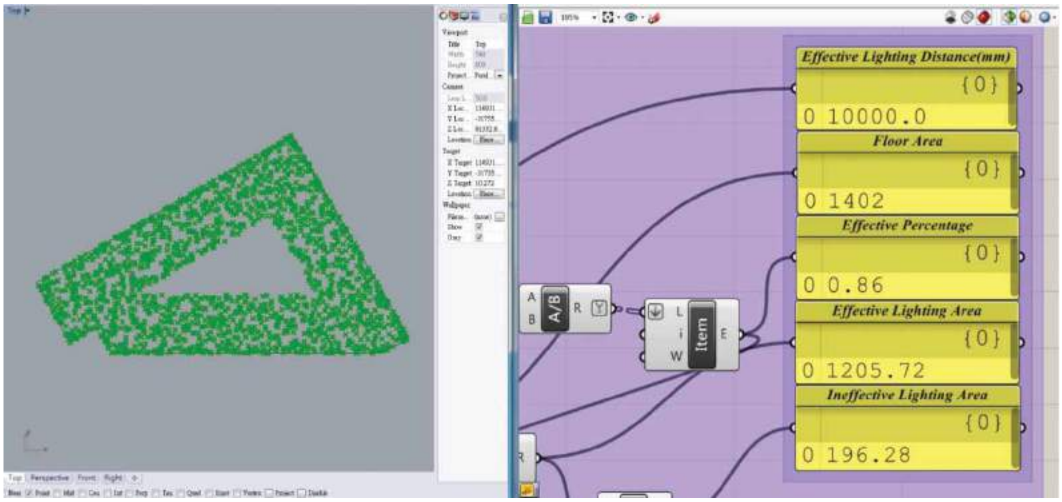

Fig. 7: Presentation of area with effective lighting and a lighting distance of less than 10 m in apartment LOD 100 massing design.

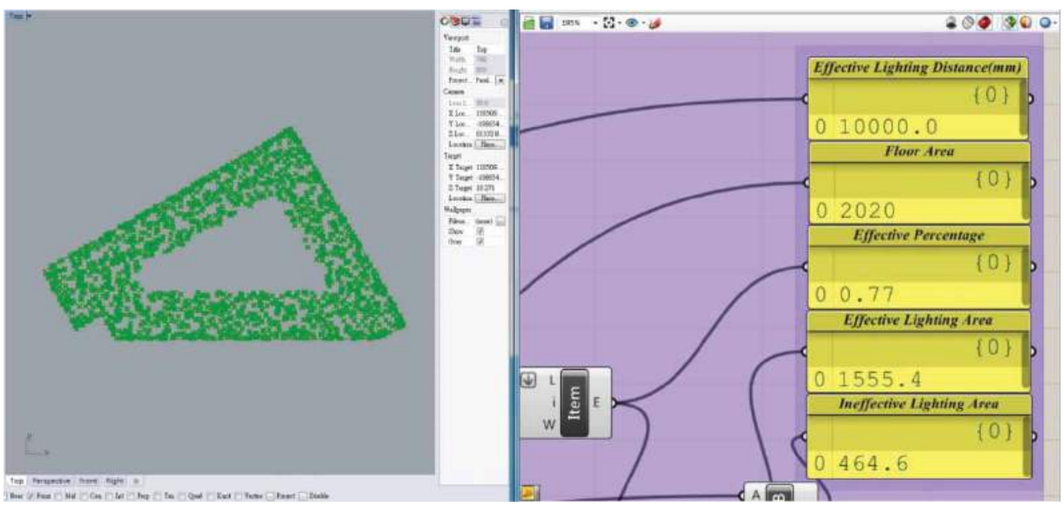

Fig. 8: Presentation of area with effective lighting and a lighting distance of less than 10 m in LOD 100 with 1.2 massing.

with poor lighting, and would make it impossible to effectively lay out apartment units within the building plan, posing great difficulties if the functional layout of the building plan was to meet the requirements of the architectural plan during the subsequent design stage.

It should be noted that the change in area with effective lighting from 86% in proposal A to 77% in proposal B is a tangible data trend, and implies a design decision-making strategy. In fact, functional layout in Fig. 9., which represents the final design proposal, is generally close to the result of analysis shown in Fig. 7.. Data generated using the Monte Carlo method is not necessarily extremely precise, and precision chiefly hinges on the number of generated points; the more points that are generated, the greater precision will be. The general data generated using parametric tools during the early design stage will not be of much help to architects seeking precise design results, such as the final lighting coefficients of each apartment unit in this case. Nevertheless, the architects had no need for precise values during the early stage. Because the early design stage is a time of generating and comparing proposals, much information will remain uncertain, such as the specific area of windows, until it has been confirmed that further design work will target a certain proposal. The rough data provided by parametric tools similar to the dashboard in this project can certainly help architects make the most reasonable decisions. For instance, the data presented by a dashboard can tell architects how increases or decreases in massing will affect the general ratio of area with effective natural lighting. In this case, the architects used this information to determine that proposal A was better able to meet the plan's functional layout requirements than proposal B. This shows that a dashboard can help architects control massing size in real time during the early design stage, ensuring that they will not have to start over, at increased cost, if plan functions cannot be laid out appropriately during the subsequent design stage.

Fig. 9: Layout of internal space in apartments following subsequent design.

3.2. Influence of the Conflict between Lighting on the Building's Western Side and Energy Conservation on Decision-making

A major conflict existing in this case involved the window opening ratio on the western side and the issue of energy conservation. Xiamen's local energy conservation regulations require that buildings' west-facing sides have a window opening coefficient of 0.2 [4]. In the situation, the architects had three possible alternatives:

A. If the window opening ratio on the western side is limited to under 20%, the lighting of apartment units on that side will be affected. In that case, as shown in Fig. 10., the effective lighting area on that side will be reduced: The green points on the western side are arranged in an irregular shape, and the area on that side with effective lighting accounts for only roughly 35.8% of the total area with effective lighting.

B. While hollow glass louvers or Low-E windows with a shading function could be used, this would cost to increase.

C. According to another local regulation, if a wall is built with indented grooves, and the width of window openings is less than or equal to the depth of the grooves, the window openings do not need to be included in energy conservation calculations [5]. Because of this, the architects were able to revise the design of the western side of the building to give it a grooved form. As shown in Fig. 11., when a grooved design was employed, the window opening ratio on the western side could achieve 100%, and the usable area with effective lighting on that side similarly approached 99.7%.

Analysis of the LOD100 modeling employing Grasshopper revealed that, if proposal A was adopted, the reduction in the area with effective lighting would either lead to poor lighting within the apartment units or prevent the requirements of the architectural plan from being met. For its part, adoption of proposal B would significantly increase costs, while not necessarily meeting the requirements of the architectural plan, unless the owner had considerable ability to tolerate higher costs. Finally, the adoption of proposal C would adjust massing in order to satisfy apartment unit lighting requirements (see Fig. 12.), while still satisfying the requirements of local energy conservation regulations.

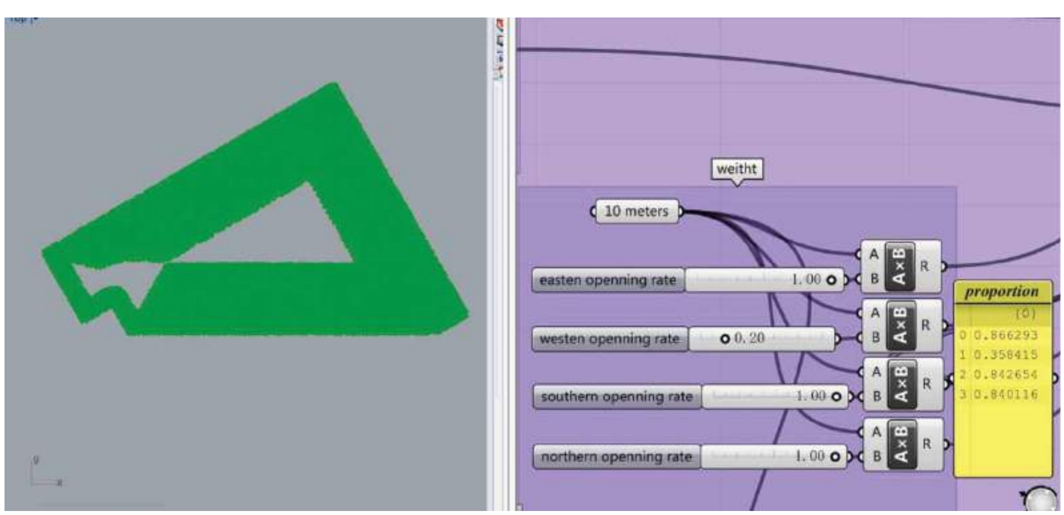

Fig. 10: Distribution and ratio of usable space with effective lighting when the window opening ratio is 20%.

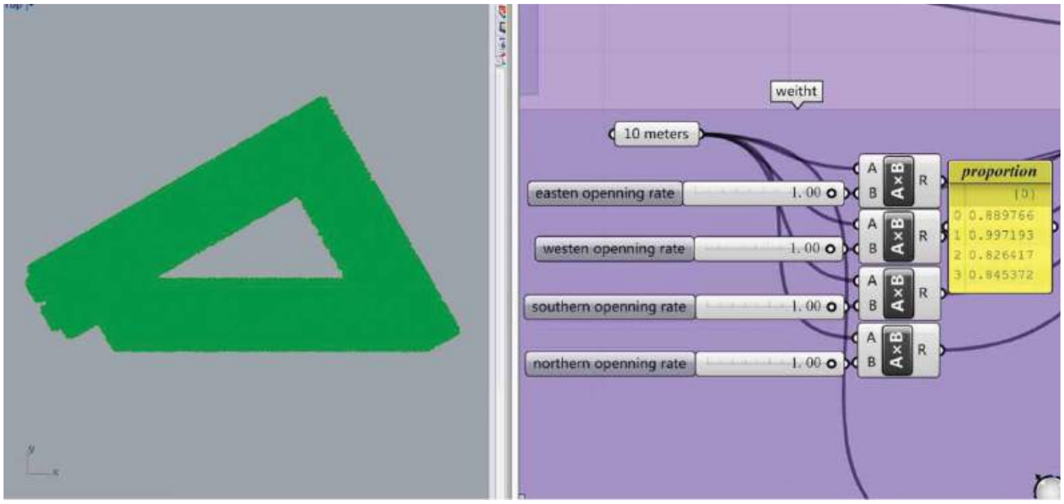

Fig. 11: Distribution and ratio of usable space with effective lighting when a slotted massing design is employed.

Fig. 12: Final handling of western side of building mass.

Although this case specified that regulations required a window opening ratio of 20%, architects can typically adjust the window opening ratio in light of different situations. With assistance from generative modeling tools, a dashboard can present the results of analysis to architects in real-time. As a result, the real-time presentation of feedback information is one of the most important features of a dashboard.

This case reveals that, with regard to decisions concerning large or small massing, or the conflict among lighting, energy conservation, and cost, generative modeling tools can be used to analyze the effects of building massing, and the results of analysis can be presented in real-time using both quantitative and visual methods on a dashboard.

4. CONCLUSIONS

In the field of BIM design processes, this study used generative modeling technology to propose the use of a dashboard to achieve the real-time presentation of assessment and analytical information. The study also used the Monte Carlo method to analyze the lighting and functional layout of an apartment building. The results of this study indicate that a generative modeling tool can perform analysis of a model, even when there is only a simple building massing, during the early design stage, and yield useful information that can help architects make decisions during this stage.

This study made the following findings: A dashboard using generative modeling technology and employing procedural information as its subject requires almost no data processing price when revisions are made. By providing real-time feedback to architects in visual, quantitative, and highly intuitive form, a dashboard can help architects to quickly revise proposals when proposals are being created and compared during the early design stage. In addition, while feedback information from a dashboard will not be very precise, it can still effectively help architects to control the direction of their design strategies during the early stage, enabling them to make correct design decisions minimizing design cost, increasing efficiency, and enhancing design quality. It is clear that the need to perform modeling employing LOD100 modeling is no less because of the model's lack of information. Based on generative modeling technology, information from BIM LOD100 modeling can be presented by a dashboard, helping architects make sound decisions during the early design stage, which will reveal the decision-making value of such a dashboard.

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REFERENCES

[1] AIA (2010), American Institute of Architects, www.aia.org/index.htm.

[2] Chang, Y.-F.; Chen, J.-Z.; Shih, S.-G.: BIM strategy used in architecture energy-saving assessment and practice, Architecture and Building Research Institute, Ministry of the Interior, ROC, 2013.

[3] Chong, Y.-T.; Chen, C.-H.; Leong, K.-F.: A heuristic-based approach to conceptual design, Research in Engineering Design, 20(2), 2009, 97–116. http://dx.doi.org/10.1007/s00163-008-0059-9

[4] Construction Department of Fujian Province: Fujian province residential building energy conservation design standards implementing rules (DBJ13-62-2004), 2008.

[5] Construction Department of Xiamen City: Xiamen architectural energy conservation design guidance, 2012.

[6] CURT (2007), The Construction User's Roundtable, www.curt.org/.

[7] Duffy, A. H. B.; Andreasen, M. M.; Maccallum, K. J.; Reijers, L. N.: Design co-ordination for concurrent engineering, Journal of Engineering Design, 4, 1993, 251–265. http://dx.doi.org/10.1080/09544829308914785

[8] Eastman, C.; Teicholz, P.; Sacks, R.; Liston, K.: BIM_Handbook_A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors, Hoboken, New Jersey, John Wiley & Sons, Inc, 2011.

[9] Monte Carlo method, http://en.wikipedia.org/wiki/Monte_Carlo_method, Wikipedia.

[10] Schlueter, A.; Thesseling, F.: Building information model based energy/exergy performance assessment in early design stages. Automation in Construction, 18(2), 2009, 153–163. http://dx.doi.org/10.1016/j.autcon.2008.07.003

[11] Shi, X.; Yang, W.: Performance-driven architectural design and optimization technique from a perspective of architects, Automation in Construction, 32, 2013, 125–135. http://dx.doi.org/10.1016/j.autcon.2013.01.015

[12] Shih, S.-G: Notes on generative modeling, procedural symmetry, and constructability of architectural design, Computer-Aided Design & Applications, 11(5), 2014, 518–525. http://dx.doi.org/10.1080/16864360.2014.902681