BUILDING PERFORMANCE SIMULATION AS AN EARLY INTERVENTION OR LATE VERIFICATION IN ARCHITECTURAL DESIGN: SAME PERFORMANCE OUTCOME BUT DIFFERENT DESIGN SOLUTIONS

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INTRODUCTION

Current green building practice has been largely advanced by an integrated design process. This integrated design process involves multiple disciplines, such as architecture, civil, mechanical, and electrical engineering. The design method heavily relies on utilizing building performance simulation to illustrate how design parameters affect the energy consumption and quality of the indoor environment before actual design decisions are made (Anderson, 2014). The architectural design tools in the integrated design process supersede traditional geometrical exploration instruments, such as Sketchup, Revit, ArchiCad, and Rhino (Negendahl, 2015). More building performance simulating tools, such as Ecotect, Computational Fluid Dynamics (CFD), Radiance, and EnergyPlus, have been developed to help architects measure building performance (e.g., natural ventilation, daylighting, solar radiation, and energy uses) in the design process and attain green building standards such as Leadership in Energy and Environmental Design (LEED). The information presented by these tools guide architects at a certain level in achieving green building goals. However, building simulation is generally beyond the architect's knowledge domain. Many architects have difficulty in understanding these technical terms and models, as well as their design implications. Therefore, specific consultants have emerged to help architects grasp the meanings of these numbers and models, which require architects to implement a high level of design collaboration and coordination (Aksamija, 2015; Gou & Lau, 2014). Simulation consultants can work in parallel with architects at the early design stage to intervene in the conceptual and schematic design; they may also work behind architects to verify the building performance after the design is finished and make their design green through technical alterations.

Most existing literature argues for an early intervention of building performance simulation in the architectural design process and explores different algorithms or models for optimal intervention (Degens, Scholzen, & Odenbreit, 2015;

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Sick, Schade, Mourtada, Uh, & Grausam, 2014; Svetlana Olbina & Yvan Beliveau, 2007). However, the difference between early intervention and late verification is often not investigated. Few qualitative studies can help understand how the building performance simulation is actually implemented, and how it influences the quality of design solutions in addition to the quantity of performance outcomes. The current research presents two case studies that compare building performance simulation as an early intervention and a late verification tool in the architectural design process, which contextualizes the building simulation research in real building practices.

KEYWORDS
green building, integrated design process, building simulation, high performance building

Building performance simulation

Green building standards propose several performance targets related to the quantitative data of building performance. These targets require the comparison of the environmental and energy performance of the proposed design and baseline based on the computational simulation. This particular requirement includes the synchronization of architectural design and simulation, as well as design quantification by complex calculation. Several performance targets are proposed in the LEED rating system. Unlike the traditional prescriptive codes, these targets may not easily be estimated by architects based on their experience or simple calculations. These performance targets not only include complex calculations of climate, building systems, and envelopes, but also involve the sophisticated simulation of the building operation mode, occupancy rate, and even user habits. Most performance targets, such as lighting, energy performance, and indoor thermal comfort, can be predicted only by computer-generated simulations (Hensen & Lamberts, 2011). Specific performance feedback and quantitative information must be provided to the design team at the different building design stages so that they can determine how effective the proposed design is and how the design can be optimized (Nguyen, Reiter, & Rigo, 2014). The optimization of building design and components according to building simulation has been investigated in many studies, and different optimization algorithms and multi-objective selection have been proposed for design teams to implement building simulation at the appropriate design stages (Wright, Bloomfield, & Wiltshire, 1992).

The quantitative performance requires a meticulous combination of the simulation software and design process. Applying these simulation tools during the entire design process can compel the design team to always relate to the building performance, thereby significantly influencing their decisions toward producing appropriate design solutions. These tools are reviewed and compared in the general research of building performance simulation (Anderson, 2014), as well as specific performance studies, such as daylighting, thermal performance, and building facades (Svetlana Olbina & Yvan Beliveau, 2007). Although the comparisons were not comprehensive because new products and new open source platforms continually come out, these studies provide an overview that ranges from the historical and technical development to selecting a suitable simulation program and performing building simulation. The current tools cover outdoor and indoor lighting simulation, sun path analysis, indoor acoustic performance, indoor thermal performance, and entire building energy simulation. Many green building credits, such as energy consumption targets, indoor daylight factors, outdoor wind speed, and indoor air ventilation rate, propose performance goals that must be incorporated into the building design and regularly verified by these tools through the entire building design process to demonstrate the goal achievement (Jensen and Nielsen 2011).

This entire performance-based integrated design process calls for the support and cooperation of simulation experts who must perform the project simulation at all design stages to provide the design team with feedback for optimizing the building performance (Gou, Lau, & Prasad, 2013). Thus, such projects entail the participation of different professionals besides traditional design professionals, including energy modelers and special consultants (Larsson, 2010). The effective implementation of green buildings depends on the complete organization of the design team equipped with the required skills to properly and successfully execute each performance (Larsson, 2009). Guidebooks and case studies on LEED implementation state that at least 14 different professionals are involved in a green building project: the architect, client, civil engineer, structural engineer, mechanical, electrical, and plumbing engineer, interior designer, facility manager, contractor, green consultant, energy modeler, lighting consultant, cost estimator, landscape architect, and commissioning authority. Some credits, such as Energy Performance, Indoor Air Quality, and Ventilation, would involve more than 10 professionals (Yudelson, 2008). These consultants or experts are expected to calibrate and utilize a broad range of simulation software applications that are available for different building performance assessments. These simulation consultants are supposed to help architects attain an increased level of quality assurance and offer efficient integration of simulation expertise and tools in the overall building process (Hussein Abaza, 2008).

CASE STUDIES

The methodology of this research is mainly based on case studies. The case study method addresses the complexities of real-life influence decisions (Kardos & Smith, 1979). It does not simply account for individual factors or their statistic significances. This method requires in-depth analyses focused on cases and groups. Two projects that represent the two working patterns (i.e., building simulation that works in parallel with architectural design and building simulation that works after the design is formed) were selected for this research by screening several green projects. The first project is the Tianjin Jiefang Roald Community Sports Center; the second project is the Shenzhen She Kou Hilton Hotel. Both projects attained top green certifications, namely, LEED Platinum and China Green Building Label Three-Star. The Tianjin Sports Center, which was transformed from an old state-owned design institute, was designed by the Tianjin Architecture Design Institute. The Hilton Hotel was designed by the architectural firm of WATG and supported by a local design company, the Architectural Design Institute of Guangdong Province. Different cooperation modes resulted in different ways of delivering green building. A project-level analysis was performed on the two selected green projects to explore their explicit attributes of the design process. The data for the case studies were obtained from document studies of design submissions and architect and consultant interviews.

CASE 1: EARLY INTERVENTION

Project Overview

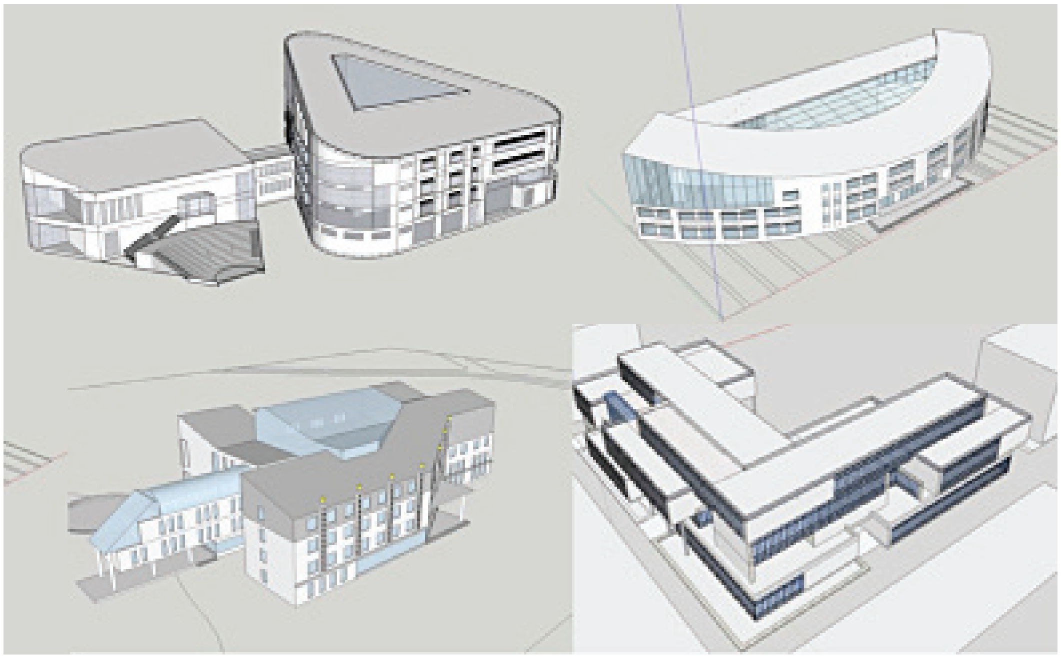
The first project is the Tianjin Sports Center on Jianjin Jiefang South Road. It has attained the LEED Platinum and GBL three-star rating. It covers an area of 10,000 m^2, with a gross floor area (GFA) of 11,500 m^2. The total building height is 23.78 m. This building was built in March 2013. The main purpose of this building is to offer reading, sports, and recreation spaces for the community. It contains a lecture hall, study room, chess room, swimming pool, table tennis room, and badminton hall. The building in Tianjin is in the cold climate zone according to the Chinese climate classification for architectural design. The target energy consumption is 50 kwh/m^2 to 70 kwh/m^2 per year, which is 60% lower than that of a conventional building in the same climate and area. Its carbon emission target is 42.7 kg CO_2/m^2 to 60 kg CO_2/m^2 per year, which is half of the carbon emissions of a conventional building. The building employs several passive design strategies, such as proper window–wall ratio, natural ventilation, daylighting, atrium lighting, and optimization of the building envelope's thermal performance, shading, and air tightness. These strategies have been tested and adjusted through simulation tools to confirm their contribution to energy savings. Active strategies were implemented in the building after considering these passive strategies. Active strategies include utilizing a ground source heat pump system, floor air distribution system, high-efficiency lighting control system, advanced devices management system, and solar panels and wind turbines to produce electricity onsite.

Design Process

Every key decision in this project was based on simulation and collaboration between architects and consultants to successfully deliver a climate-responsive building. The architects could easily access different information on the physical performance, energy use analysis, construction cost estimation, construction sequencing, building code compliance, and space utilization during the design process because of the building information modeling platform. This tool type can improve the utilization rate of databases and help to develop a high-quality plan. This design process is completely different from the traditional individual-oriented decision-making methods and linear design process. Four architect groups were assigned to propose their designs at the conceptual design phase. The architects provided four different master plans, including triangular prism type, Z-type, semi-circular type, and L-type (Figure 1). The buildings were modeled through different simulation software, and then basic technical parameters were generated.

The design team performed four rounds of quantitative analysis, including the building envelope's thermal performance, natural ventilation, daylighting, and solar shading (Figure 2) according to the ambient natural environment and basic data of the four plans. The solar heat gains of four elevations of the different plans were simulated by STARCCM+ for winter and summer conditions. Results of the simulation analysis indicate that the triangular columnar and semi-circular designs of the building obtained more heat in winter than in summer. The

FIGURE 1. Four building plans proposed by the project architects.



building envelopes of the Z-type and L-type designs exhibited relatively poor performance. The simulation consultants also employed CFD software to conduct wind analysis. The wind pressures of the different façades were calculated, and the effects of utilizing natural ventilation solutions were assessed. Analyses show that the Z- and L-type designs had larger surfaces exposed to wind during seasonal transitions and performed better in terms of natural ventilation. A simulation analysis was also performed to obtain a reasonable arrangement of the outdoor venues. Outdoor space ventilation was improved under semi-circular and triangular prism types through a quantitative analysis utilizing the software. No evident vortex was observed around the building, which helped in the dispersion of air pollutants. The consultants adopted STARCCM+ software to calculate the radiation amount outside the window surface and estimate the interior brightness. The indoor lighting conditions of the different plans were determined. The experts also attempted to decrease the size of the north rooms to obtain additional hours of sunshine. The triangular and semi-circular designs minimize the rooms that face north. Ecotect software was employed to analyze the shadow generated by the sun.

A strict scoring rating system (Table 1) was developed according to the analysis results to evaluate the four design schemes. The indicators include natural ventilation, daylighting, building envelope thermal performance, building configuration coefficient, window-to-wall ratio, impacts on the surrounding environment (i.e., lighting and air ventilation environments), building layout, terrain suitability, and integration of passive strategies. The selection involved scoring of the above 10 indicators. The most suitable form among the four design schemes was determined. Most of the rankings and ratings were based on the analysis of the quantitative data obtained by building simulation. The semi-circular plan was selected for further design process after the scoring and balancing. This plan had comprehensive advantages and outperformed the other plans.

FIGURE 2. Building simulations on the four building plans (1: solar radiation; 2: natural ventilation; 3: sun path and shading; 4: daylighting).

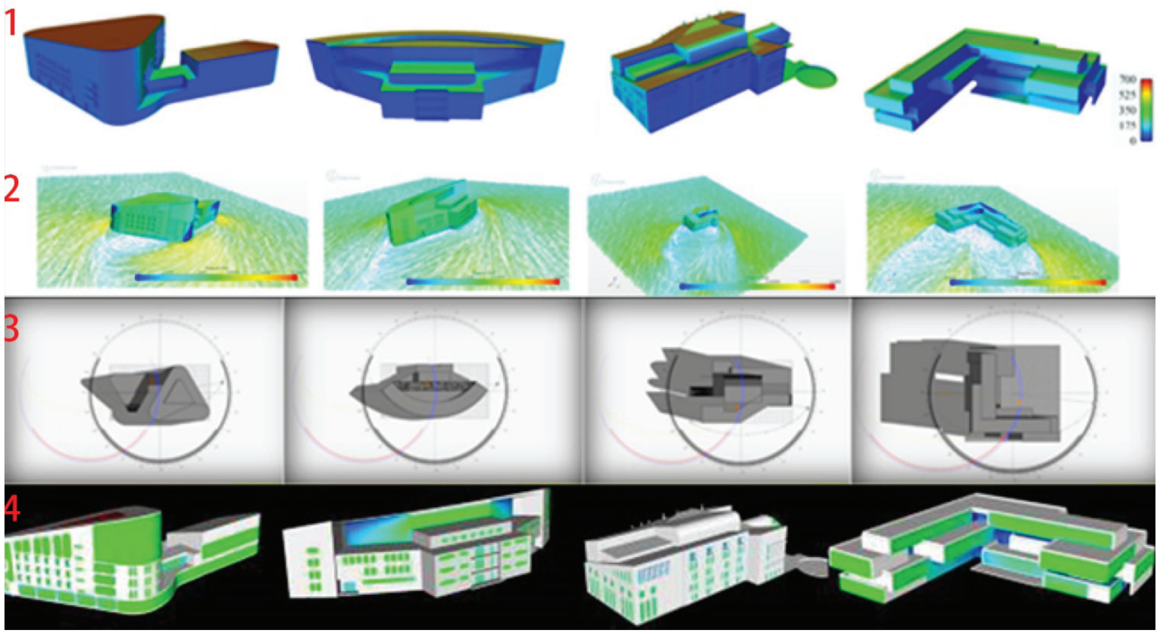


TABLE 1. Scoring process to select the best concept design.

	Triangular columnar	Semi-circular	Z-type	L-type
Natural ventilation	3	4	2	1
Daylighting	4	4	3	2
Building envelope thermal performance	3	4	2	2
Building configuration coefficient	3	4	2	1
Window-to-wall ratio	2	3	4	1
Impact on the surrounding environment (lighting)	3	4	4	3
Impact on the surrounding environment (air ventilation)	4	3	2	1
Building layout	3	2	4	3
Terrain suitability	4	4	3	3
Integration of passive strategies	4	4	3	2
Final score	**33**	**36**	**29**	**19**

A problem in the optimizing phase of the selected semi-circular design scheme was encountered in programming the functional spaces because of the low interior space utilization. Thus, this plan was optimized into a fold-line type. Further energy analysis was conducted based on the new adjustments. The simulation consultants verified the impact on the building envelope thermal performance and heating and cooling loads on the Heating Ventilation and Air-conditioning (HVAC) system after the optimization of the building form. No significant changes were caused by the new adjustments. Another important simulation-based design is on daylighting. The simulation in this project initially confirmed that the building met the green building requirement that more than 75% of the regularly occupied areas must have a daylighting factor higher than 2%. However, more than 90% of the regular areas must have a satisfactory daylighting factor to attain more credits and higher performance. An atrium was then designed, and functional rooms were arranged along with the atrium corridor in every layer so that more spaces can receive natural light. The simulation expert conducted another daylighting analysis of the entire building after refining the building plan. Figure 3 shows the atrium effects with skylights added to the building. The simulation confirms the effectiveness of this strategy in helping this building meet the optimal daylighting performance. Besides the daylighting performance improvement, the atrium and skylight also effectively improved the natural ventilation performance (Figure 4). The heat gathering in the atrium can be released outdoors through the skylight.

FIGURE 3. Effectiveness of the atrium and skylight on the daylighting performance.

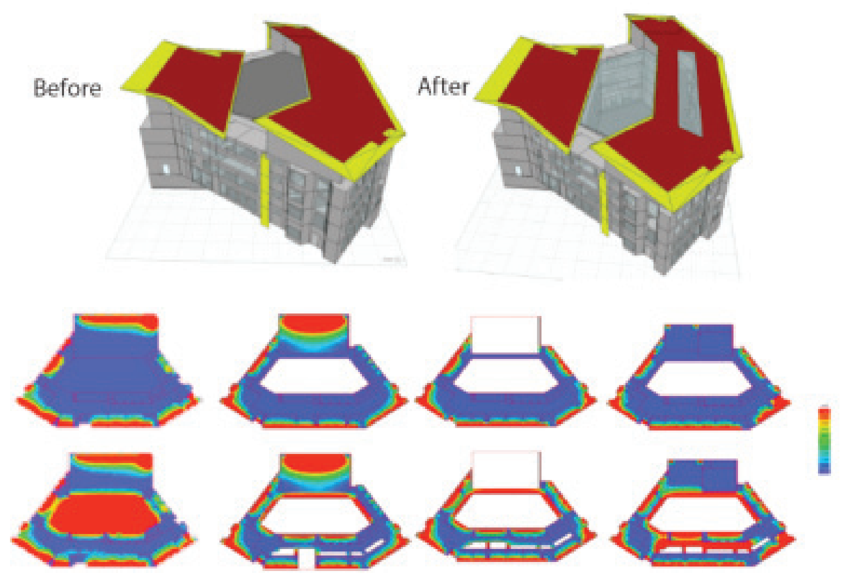
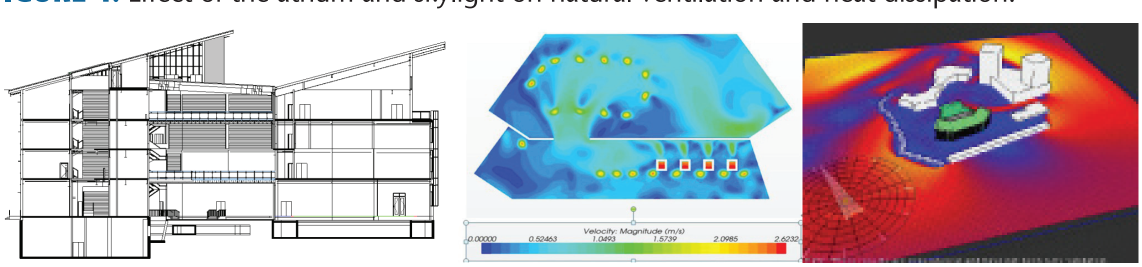


FIGURE 4. Effect of the atrium and skylight on natural ventilation and heat dissipation.



Simulation consultants and architects worked together, further refined the model, and performed a final energy simulation after the design development stage to determine if the project accomplished its target. Besides improving the building design, the simulation was also utilized to instruct the landscape design and aesthetic design. The allocation of trees and plants was according to the air ventilation conditions around the site in different seasons. The designer opted to plant evergreen plants or hedges in the northwest and northern parts to lower the impact of cold air and heating loads according to the wind conditions in winter. The designers opted to plant tall deciduous trees in the south to facilitate ventilation, lower the solar heat gains, and weaken the highway noise according to the wind conditions in summer. The designers also opted for low plants grown in the southwest area to ensure natural ventilation during the season transition. The simulation also suggested selecting wall colors to enhance the building envelope's thermal performance. Hence, the building simulation played a key role in guiding the architectural design phase. The entire coordination process required the architect to select and make optimal decisions in response to different building simulations, advice of simulation consultants, and the requirements of green building standards.

Architects' feedback

The above analysis indicates that the building simulations significantly affected the design process and working pattern of the architects. These simulations were integrated as a key component in the green building design process. An interview was conducted to explore the architects' feedback on the integration of the simulation software and cooperative working mode.

Question: What is your general view of the building simulation in this project design process?

"The simulation software in this project offered strong quantitative data to support passive design strategies. These data not only enhanced the architects' confidence, but also allowed the developers to easily accept them. Even if we wanted to prioritize the passive design in other cases, convincing the developers or clients is difficult due to a lack of evidence."

Question: How did the simulation affect your design concept? Did it restrict your creativity?

"The simulations offered effective assistance and helped us reach our initial goals. The simulation's role in this project is indispensable and irreplaceable. We relied on them to guide every key decision. I do not think it affected our design plan or limited our creative ideas. In fact, we cannot implement our creative ideas without the simulations. For example, the nature ventilation system plan would not have been applied if the simulations did not offer effective guidance or strong quantitative evidence. I think that the simulations provided positive support in every key decision. Simulations must be applied if sufficient time is available for a project."

Question: Have you identified barriers to understanding and implementing the building simulation?

"I did not perceive any barriers brought by the quantitative simulation. The performance-based approach in this project was introduced at the pre-design stage. Those performance requirements were deeply integrated into our design plan because we considered many passive design strategies and energy-efficient technologies. We also utilized different simulation software to evaluate

our design plan during the different design phases. We obtained accurate results from the simulation software and confirmed their consistency after finishing the design plan. Our design team is highly confident with our plan. Only minimal adjustments were required in the design development phase. I believe that the entire design process addressed these requirements not as an added process only after the building design plan was finished."

Question: Are you satisfied with the way the strict scoring system was utilized to select the best building design scheme from the four plans?

"I think the scoring method provided a means for us to appropriately select among the four design plans. Although the energy efficiency aspect received more attention than the other aspects because its primary goal was a net zero energy building, the architectural design aesthetics were still some of the most important aspects in the scoring system. Other projects can also adopt the scoring system, but the weighing of the energy saving aspect can be lowered. I think that the energy efficiency aspects did not prevent the architects from pursuing a suitable building form and shape or developing a functional layout. They merely added several building performance aspects for the architects to consider and balance. I think the responsibility of architects is to determine better solutions despite different limitations and requirements."

Question: Do you think the architects' power and decision-making abilities were weakened by the building simulation?

"I do not think that the architects' power and abilities were weakened. By contrast, I think more forms of assistance, including multiple experts and simulation software, were integrated into the design process and helped us to explore more creative ideas and design a better building. Although conducting several simulations was rather time consuming, these actually provided useful guidance and effective strategies to optimize the building design plan. These simulations also enriched knowledge in other disciplines and allowed the architects to consider aspects that may have been previously ignored during the design process. We would not have reached our goals and completed this high-performance building without these discussions and information sharing. We thoroughly enjoyed this cooperative working mode. This new working pattern will become popular in the future. Architects must adopt and maximize this pattern."

Question: What are the negative aspects of the building simulation-based architectural design process?

"Simulation was overused to guide the project design. Although it offers strong evidence for the designers, it is time consuming and at times can be a waste of human resources. Many design decisions can be made according to the qualitative analysis and the architects' experience. However, these analyses might sometimes not serve their purpose."

The architects had highly positive attitudes toward building simulation, except for the overuse of building simulation in this project. They considered the simulation useful and effective. It not only assisted them in improving building performance and reaching the original targets, but also supported them in realizing their design concept. They did not believe that their roles were weakened. They appreciated the aid provided by the simulations and related professional consultancy. They believed that the project was better than conventional buildings, and its performance is worthy of further optimization. Thus, the architects were extremely supportive of this project and the design process.

CASE 2: LATE VERIFICATION

Project Overview

The project for this case study is the Hilton Hotel on She Kou Tai Zi Road in Shenzhen. The hotel currently has a GBL three-star and LEED Platinum rating. It encompasses an area of 23,654 m^2, with a GFA of 50,920 m^2. The total building height is 60.8 m. The hotel has 14 floors. It was built in May 2013. This building offers 320 guest rooms, a meeting room, a banquet hall, several restaurants, and recreation spaces, such as a swimming pool, a spa, and a business room for its guests. This building in Shenzhen is located in a subtropical climate zone according to the Chinese climate classification for architectural design; this zone has warm winters and hot summers. The performance requirements for buildings in this area are similar throughout the year because of the high temperatures and slight seasonal variations. The important passive design strategies for a building in this climate zone are continued and effective natural ventilation and humidity reduction. Suitable shading systems are necessary strategies to maintain indoor comfort. Moreover, a proper building shape and efficient wall insulation system are necessary to lower the use of air conditioning during the summer. This project did not start from the application of different passive design strategies. Instead, its major consideration was the seascape resource, which includes utilizing the configuration and layout of buildings and other strategies to maximize the sea views. The symbolic effect of the building, architectural style, and impressive facade were also the primary foci of this architectural design scheme. An energy-saving design was merely considered to meet the certification level, which was mainly implemented by the selection of building components and equipment and has minimal impact on the building design plan.

Design Process

The design process implemented at the Hilton Hotel is currently the most popular architectural design process. However, the participation of a green building consulting company was introduced to the traditional design process to obtain the best green building certifications. A green building consulting company participated after the completion of the building scheme. Green building consultants conducted different simulations, including those on thermal performance, indoor and outdoor air ventilation, interior day lighting, outdoor noise, and the heat island effect, in accordance with the green building certifications.

Three building plans were proposed in the concept design process to present attractive appearances of the building shape and style (Figure 5), including the dual L-type, Y-type, and arc-type. The main concerns during the selection process among the three plans were the building shape and its metaphorical meaning. The dual L-type plan was selected and developed. The design metaphor is two fishes playing in the sea: two pairs of L-shaped towers that face the sea were designed according to the fish shape; the combination of the balcony and decorated panel forms the building facade to present a scale-like external appearance (Figure 6). The playground under the building was designed to reflect the irregular sea rocks. This design concept and building shape were eventually selected for the schematic design.

The building environment and energy simulation software in this project did not cause significant changes and provided guidance in the building plan. The major role of these simulations was to provide quantitative support on whether the building meets the green building assessment criteria. The building environment simulation of this project included outdoor

FIGURE 5. Three concept designs for the best capture views.

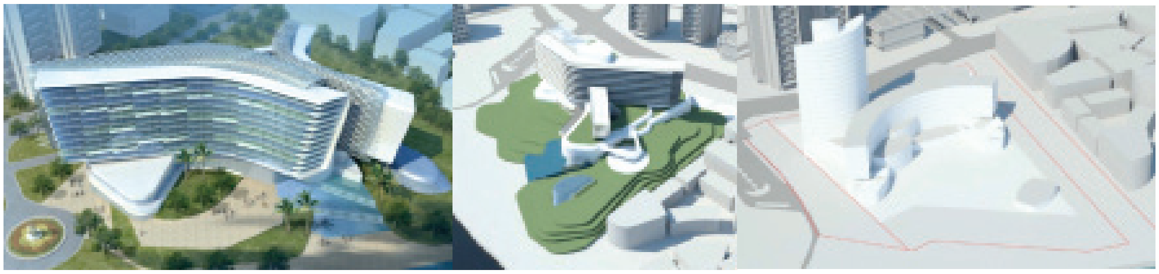
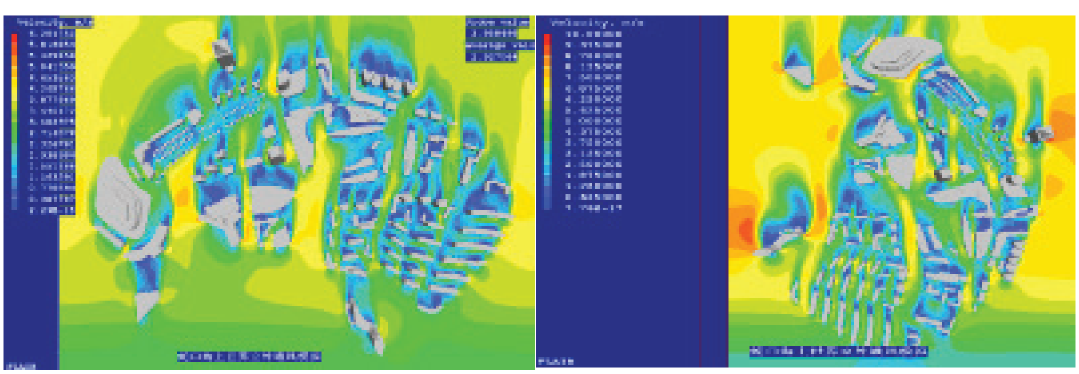


FIGURE 6. Metaphor of two fishes playing in the sea.

daylight simulation, indoor and outdoor air ventilation assessment, indoor lighting simulation, and noise simulation.

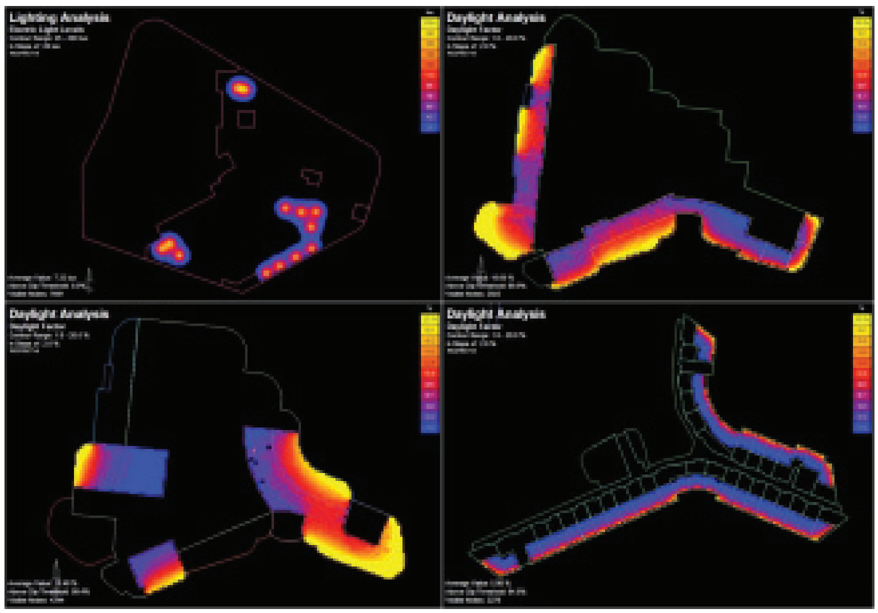
The natural ventilation requirements in the green building assessment criteria were as follows: (1) performing wind simulation for the surrounding environment of the project to confirm if the shape, orientation, and layout of the project are conducive for natural ventilation and ensure that the project does not affect the natural ventilation of the surrounding environment; (2) assessing if the wind speed distribution is acceptable and comfortable; and (3) evaluating the wind pressure on each side of the project's envelopes for indoor air ventilation. Figure 7 shows that the outdoor air ventilation of the site functions well in the case of a prevailing southeast wind. Two wind ventilation channels were formed in the hotel area and improved the ventilation in the hotel region. Moreover, the wind pressure between the building front and rear surface can reach desired targets and is conducive for indoor natural ventilation.

FIGURE 7. Wind environments at pedestrian levels.



A daylighting simulation was conducted to verify that the daylight factor of more than 75% of the regularly occupied space in the hotel can meet the 2% threshold. The daylighting simulation had certain effects on the building design, such as selecting the position of lighting pipes at the ground floor. Figure 8 shows that 14 sets of lighting pipes were installed in the garage at the ground floor to enhance the daylighting performance. The other spaces can largely meet the performance threshold because of the large area of transparent windows and the alignment of the main occupied rooms toward outside views.

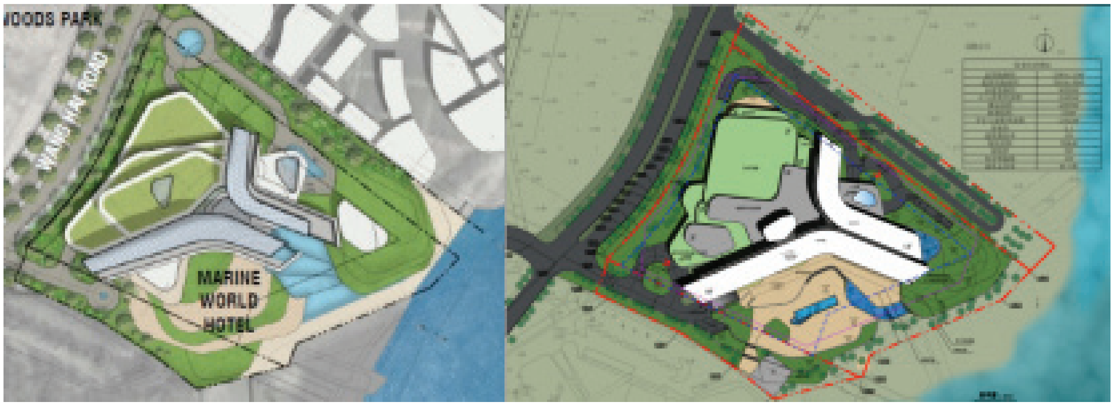
FIGURE 8. Daylighting performance analysis based on the building floor plans.



The simulation consultants emphasized the issue of excessive cooling loads due to exposure to solar radiation after confirming the dual L-type plan. Architects agreed that separating the two towers was energy intensive. The two building towers also utilized the atrium for connection, which was unsuitable for space utilization. Although the one-side corridor design provided better views, it did handicap the energy efficiency and space utilization. Therefore, the architect combined each side of the two buildings in the following optimization process. The southeast part of the building has a bilateral corridor, which means that a part of the corridor has rooms on both sides, and the rest remains the same. The project was not only able to retain the two separated building forms in this manner, which represents the architect's design philosophy, but could also consider the building energy efficiency factors to a certain extent (Figure 9).

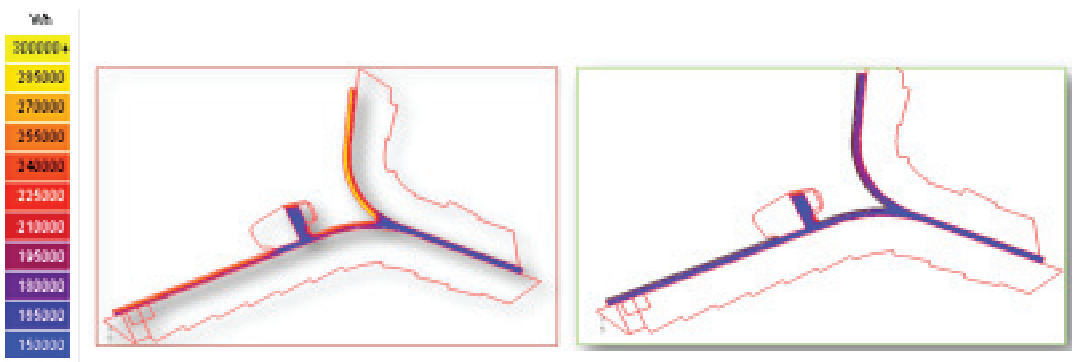
The simulation consultant performed an analysis and comparison of the thermal comfort and solar heat gain in the guestrooms and corridor outside the guestrooms after the revision. The consultants identified excessive solar heat gains due to the large windows and proposed exterior shading devices. The result also shows that heat gain with exterior shading could be 53.8% lower than that without exterior shading (Figure 10). This result also indicates that the shading devices could significantly lower solar radiation and sharply decrease the energy consumption of the air conditioning system. The simulation consultant suggested utilizing adjustable external shading for the northwest façade. However, the architects believed that exterior shading would seriously affect the facade aesthetics. The conflicts were discussed many times; the architects

FIGURE 9. Building plans' alterations.



ultimately retained their perspective. The architects agreed to employ a few shading devices that would insignificantly affect the facades as a concession. The length of these devices did not reach the length requirements proposed by the simulation consultants. These few exterior shading devices were only applied to obtain the green building credit.

FIGURE 10. Solar heat gains without and with exterior shading devices.



The thermal performance of this project generally met the requirements of the green building standards after the adjustment of relevant architectural parameters by the simulation consultant. These requirements are the shape coefficient, window-to-wall ratio, heat transfer coefficient, and shading coefficient of the exterior windows. The simulation consultants employed Energyplus software to perform an overall energy consumption analysis of the hotel. The result shows that the total energy consumption of the designed building is approximately 75.5% less than the baseline building. The simulation consultant verified the final architectural design plan and submitted the verification for green building certifications at the construction stage. This process is relatively common. Building energy and environment simulations are mainly conducted at the design development and construction phases. Therefore, the simulation results played limited roles because they did not provide guidance for the concept and schematic design. They instead focused on providing suggestions for the selection of the building materials and equipment. Many experts have misunderstood that green building design refers to the selection of building components or high-efficiency service systems, including lighting, HVAC, and solar power systems, under this current scenario. The role of green building and simulation consultants is not to help architects design a climate-responsive building. These professionals instead serve to obtain certification levels according to the relevant requirements. This point-purchasing method of building simulation is easy to implement and does not require changing the traditional architectural design process.

Architect's feedback

Question: What is the role of building simulation in the architectural design process for this project?

"Our design plan was not adjusted by the simulation software. The guidance for the green consultant was mostly about the selection of materials for the building envelope and several active strategies, such as outdoor permeable surface, rain harvesting system, and green roofing. I did not perceive any differences between a green building and a conventional building during the scheme design phase."

Question: What are the performance effects on the building concept and scheme design in this project?

"I did not perceive any changes at the scheme design stage. Those performance targets were actually introduced after the design was confirmed by the design team and developer. The performance requirements did not limit the architect's creative design nor significantly change the architect's working pattern. We only had to follow the list provided by the simulation consultant, added several green technologies into our design plan, and selected appropriate building materials for the green building certification in this project."

Question: Are you satisfied with the building simulation in this project?

"The simulations were not integrated into our scheme design process. The role of these simulations was to provide quantitative reference about whether the building meets the green building criteria. I understand that these simulations are required by green building certifications to assist the architect in considering the building performance and energy consumption situation during the design process. However, these simulations cannot provide useful guidance for the building plan in most cases because quantitative data can only be obtained when the building plan is almost finished. Moreover, the results cannot be visualized and cannot offer practical suggestions for revision. I seriously doubt their effectiveness at the scheme design stage. The hysteresis of these simulations indicates that they cannot help architects design a building plan or evaluate better solutions. The building design depends largely on the architects' abilities and sufficient experience, which cannot be replaced by quantitative simulation software."

Question: The simulation consultants proposed many passive design strategies, but these were rejected by the design team. Why were these strategies not accepted?

"The passive design strategies significantly affected our original building plan. For example, adding exterior shading devices would have a negative effect on our facade, and raising several skylights in the elevator aisle area could cause harmful effects on the main structure. Although these strategies can improve the building performance, they cause more harm than benefits. These passive design strategies must be considered as a part of the building design because they are mainly related to the architects' scope of work and must be determined at the scheme design phase. The introduction of passive design strategies would always be denied when the building plan is settled because

they can require major modifications, which are time consuming and uneconomical. The successful adoption of these strategies must be initiated by the architects at the initial building plan."

Question: What are your opinions on the quantitative building performance simulation?

"I completely agree that building performance simulation is an essential part of building design, including daylighting, thermal comfort, and air ventilation. We always consider these factors during the building design process even without the green building requirements. The difference is that these rating systems require quantitative analysis. However, we merely depend on our qualitative analysis or past experience. These quantitative performance data cannot be visualized and utilized to guide the building design directly. The architects assessing their design plan in a quantitative manner given their rich experience is impractical. Simulations are unavoidable when it comes to quantitative data. Capturing different simulation software is difficult for architect. Different simulation experts must be involved at the scheme design phase, which may require a reform of the organizational structure of architectural firms. With such a short design period and high-intensity workload of the architectural design, I think that this type of working pattern cannot become reality."

All of the architects' opinions were negative. They did not consider such simulation as helpful. They instead believed that it caused many barriers to their design. Different simulations must not affect the scheme design process. They also insisted that architects must dominate the design process to ensure the design quality and consistency of the design concept. They believed that passive design strategies must be applied in the building plan based on the architects' observation and experience. They also tended to have a negative attitude toward the requirements of quantitative performance data.

DISCUSSION AND CONCLUSION

A thorough examination of these two cases shows that the performance results of these projects are different according to Integrated Design Process theory, even though they all received the highest level of green building certification. The attitudes and evaluations of the participating architects involved in these two cases are also completely different. The impact of building simulation on the architectural design is significantly reflected in Case 1. The simulation influenced the architectural design at the beginning of the concept design and throughout the entire design stages: architectural configuration, architectural design strategy optimization, and selection of building systems. This project clearly reflects how the different environmental and energy simulation software affected and changed the traditional design process guided by the architects' experience and developers' preference. The most prominent performance of the quantitative environmental analysis in the entire design process is the selection of the architectural plans. The design team employed a comprehensive indicator-scoring method in this process, which is significantly different from the traditional means of building plan selection. The following section presents the detailed project selection process. The building simulation and related consultancy in Case 2 did not significantly affect the building design plan, such as the building shape, orientation, facade, and layout. The design team treated the green building design as merely an added technical standard required for several "green" strategies to satisfy the certification requirements. These new consultants were hired to implement the new technologies and not to guide the design plan in the architects' opinion. The consultancy effectiveness was demonstrated in the technical design phase. The experts applied complicated technologies during this phase to accomplish an optimal building performance.

Both projects attained the top-ranked green building certifications. Therefore, differentiating the early intervention from late verification is difficult based on building performance outcomes. They all attained a certain level of energy savings and resource efficiency. This study argues that the real difference exists on the design solution. Early intervention can produce real climate-responsive green building, whereas late verification can only lead to technocratic solutions. This scenario is worse under the point-chasing culture of green certification. Many simulation consultants currently utilize the green building rating systems as an assessment tool to obtain certain credits and attain certifications. Thus, building strategy choices and solutions are based only on economic convenience and viability. The second project is an example, where the performance targets and energy efficiency concept do not affect the building scheme design, and these targets are only regarded as added components for green building credits. The different interventions also significantly affect the architects' perception of building performance simulation in their practices. The first project is a suitable example of the positive influence of building simulation on the architectural design process, wherein architects expressed their positive feedback on adopting building performance simulation at the early design stage.

This study not only questions the point-chasing culture of current green building rating systems, but also argues for an early intervention of building performance simulation in the architectural design process. LEED v4 has already started to address this issue. The new Integrative Process Credit introduced in LEED v4 requires design teams to investigate energy- and water-related credits at the early design stage. Moreover, building simulation methods must be employed to explore the synergies and effects on building systems, which involves performing holistic investigations rather than utilizing targeted, credit-specific calculations that now characterize other LEED credits. The design team must not only provide quantitative results to obtain this credit, but also offer design process documents of at least two design strategies and the comparison process before the schematic design is confirmed. This evidence proves that the main focus of green building rating systems is shifting from simply obtaining accurate quantitative goals for the decision-making process. The present focus is to encourage the selection of multiple design plans and optimize the design solutions. Moreover, the focus of the building design process is considered as an effective means of avoiding the "point-chasing" phenomenon.

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