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Abstract. The research team completed a three-year project funded by the Teaching Development Grant (TDG), which aims to explore, develop, and support a long-term strategy to apply scientific visualization to teach the core architectural curriculum in environmental technology and building performance design. An inter-institutional collaboration was formed to draw on the knowledge and experience of colleagues in related disciplines to develop innovative teaching pedagogy and resources. The project has made a great impact in improving the teaching and learning environment in our department. In the concerned area, and in this paper, we would like to discuss the methodology and computational environment developed and highlight the findings in the following areas: Contribute to the development of curriculum of Technics studio, New curriculum on performance-based design and planning, Collaboration with other design schools and professional institutions, and Evaluation method for the project development.

1. Introduction

Predicting and evaluating building performance plays an important role in the training of responsible architects. Building performance includes issues such as: structural stability; acoustic quality, vibration, and noise damping; natural and artificial lighting; thermal comfort; ventilation and indoor air quality; energy efficiency and life-cycle cost analysis.

These types of analyses are often laborious, non-intuitive, and non-graphical. As a result, these important issues do not arouse the enthusiasm
of architecture students, who must devote considerable effort to develop tangible design representations such as drawings and models. The ever-increasing power, sophistication, and availability of computational hardware and software offer possibilities to improve the analysis, visualization, and pedagogy of these issues.

The research team has explored, developed, and supported a long-term strategy to apply scientific visualization to teach the core architectural curriculum in environmental technology and building performance. Our goal is to provide all of our architecture students with the knowledge and technical skill to apply scientific visualization to advance the performance of buildings.

2. The Impact of the Project in Improving the Teaching and Learning Environment

2.1 CONTRIBUTE TO THE DEVELOPMENT OF CURRICULUM OF TECHNICS STUDIO.

In the past one and a half years, responding to the development of building professionals, the Department of Architecture has re-engineered the studio education process. Firstly, we offer the vertical studio structure to our students; secondly, we offer specific technical subjects to our students with extensive technical expertise and infrastructure supports.

Based on the technical skills and infrastructure developed in the TDG project, upper year undergraduate students and Master of Architecture students start to apply these skills to explore the environmental issues in architectural design. For example, there are both MArch 1 and March 2 students to integrate the CFD simulation to assess their natural ventilation strategies for indoor thermal comfort. The goal is not only to provide these tools as an assessment mechanism for our design students, but also to introduce the students a new aspect to consider their design. In many cases, students have developed a better understanding of their building environmental design with the surrounding context by viewing the airflow diagram of a building section.

Although the curriculum of technics studio is still at its early stage of development, the new approach has been introduced in the visit to different architecture programs (e.g., Tianjin University and Tongji University) and attracted great attention from these programs. Meanwhile, the student sample works in this area has also been introduced to the academic visitors of the department such as Dr. Chu Zhi Nong, Director General of Education, Science and Technology Department of Liaison Office of the Central People's Government in HKSAR.
2.2 NEW CURRICULUM ON PERFORMANCE-BASED DESIGN AND PLANNING

Performance-based design has been identified as one important approach to establish an earth friendly built environment for the future. However, the qualitative design approach adopted by the conventional studio education encounters great difficulties to facilitate this process, and it is always difficult to illustrate the relationship between the consequence of a design decision and the surrounding urban context to design students. Applying heuristic environmental design rules to early stage design decisions from time to time brings unsatisfied outcomes, and the high density urban context of Hong Kong further complicates the issue. Thus, understanding the embedded knowledge associated with the high density environmental friendly urban/building design will be the key factor in our education to be introduced to our next generation urban and architecture design students.

The technical expertise and scientific computation infrastructure developed through the TDG project has laid important foundation to serve this important design education need. The achievement in this project is not only on the development of scientific computation capability on building environmental simulation, but also on the development of methodology and pedagogy for integrating scientific simulation into the design curriculum to fulfill the needs of future practice.

Although there are other building science research centers (e.g., BRE, LBNL), which have devoted significant research efforts on building environmental aspect, their works cannot meet the needs of Hong Kong and other local design school education needs in the following two folds. Firstly, there is no clear methodology given to implement the research findings into the design studio education, and the knowledge representation framework established by building science researchers cannot effectively cope with the dynamic design decision making process. Secondly, the high-density high-rise Hong Kong urban context around world represents different challenges to our students and professionals, and required technical expertise and methodologies to conduct problem solving is significantly context-based, localized, and multi-dimensional.

Owing to these reasons, the TDG project has spent great amount of time to study the possible approaches to integrate environmental science simulation into studio design education. Based on student's education background, design intention, context of project environment, pilot projects have been carried out to investigate the pedagogy and approaches. The development of technical expertise and scientific computation infrastructure is always guided by the direct observation and user feedback of these case studies. "Selecting" and "configuring" the to support the design process needs is one of the key issue explored in the whole project period, and this exploration has been further extended outside the original project period and funded by other resource.
One good example to highlight above issue is to on the sun shadow exercise introduced to students for their design option evaluation. Based on the previous experience accumulated by the task group, Radiance has been selected by the team to generate the comprehensive sun shadow analysis for the user activity zones planning, and students are taught the necessary operation skills in order to analyze their design options. However, after discussing with our design students, the team found out that the original recommended approach requires a rather long learning curve and provides many different types of information which might not directly relevant to students' design evaluation. Based on the feedback received, the research team starts to look for different kinds of software package which is design problem solving oriented instead of science and technology oriented. At last, the software (EcoTech) used for the studio design could provide designers proper level of details regarding the interblock sun shadow planning, but not requires designers to spend too much time to build up a high-accuracy scientific model which contains much unnecessary details.

If we consider that "aware of, understand, and be able to" are three important levels recommended by the international architectural program accreditation organizations in design education, the approaches and techniques developed in the TDG project provides studio tutors means to lead students to go through different levels of environmental design subjects. Especially, when students compare the simulation outcomes with the direct observation made on the real context, it helps students establish critical links between abstract architecture form issue with the building sub-system performance according different technical considerations.

Following this line of thinking, a case study is conducted with our upper year students for assessing the usage of the public open space in Hong Kong public housing estates. Conventional activity mapping and post-occupancy evaluation are conducted for getting the conventional design configuration related information. On the same time, the team conducts the urban wind simulation and interblock shading simulation to highlight the environmental aspects of the open space. Then students draw their findings from both traditional architecture design point of view according the humanity survey and urban thermal comfort point of view based on the scientific computation.

2.3 COLLABORATION WITH OTHER DESIGN SCHOOLS AND PROFESSIONAL INSTITUTIONS

Collaborating with final year students thesis project from Building Construction Department of City University, the main goal is to assess how value-added down-stream design activities could be influenced and facilitated by the learning opportunities and scientific computation provided by the TDG project. Students from CUHK focus on the overall strategies in getting environmental design features integrated with the building layout, and
students from CityU mainly focus on the development of the active or passive control mechanism to support the selected design features. One interesting observation made in this joint exercise is that how discipline-based conceptual framework (in this case, architecture and building services) affects the development of simulation model and the interpretation of outcomes. Media and format also play an important role in representing data for design decision making purpose.

Collaborating with the upper year students from the Product Design Group of the Design School of Poly University with the supports from Kinetic Design Group (KDG) of MIT, a joint design project will be issued to both university students in the coming Spring term. The nature of the project will be a multi-discipline project, and is to explore the potential to integrate the outcome of building performance simulation with the kinetic based building product design for improving the livability. One of the important aims is to investigate what kind of roles that scientific simulation could play in the recursive design cycle for both disciplines.

Since there is also a need on the knowledge on how to run a performance-based design studio for other design schools and professionals, under different occasions, public lectures and continuing education courses have been given to other design schools and professional associations. The main focus of these lectures and courses is not on the scientific computation technology or infrastructure, but on the methodologies to implement performance-based studio in their own design context. In recent one year, for academic field, the research team has introduced the TDG works in School of Architecture, Tianjin University (China), Architecture Design and Research Institute, Zhejiang University of Technology (China), Faculty of Architecture, Rangsit University (Thailand), Department of Building Simulation, Lawrence Berkeley National Lab, Berkeley (USA). For building performance group, the research team has been invited to give talks in Green 2001 Symposium, Hong Kong Institute of Architect; Green Building seminar, Building Innovation Unit (BIU), Buildings Department, HKSAR; meeting with Science and Technology Committee of the Ministry of Construction. Under the request of BIU/BD, a seminar and training workshop is organized to provide continuing education to the building controllers who are looking after recent released JPN1 and JPN2 for Hong Kong green building design.

2.4 EVALUATION METHOD FOR THE PROJECT DEVELOPMENT

From the pervious design behavior research conducted by the Artificial Intelligence or Cognition Science from other universities, it has been indicated that there is a lacking of reliable methodology to assess designer's mental process. Because architecture design problems in general are ill-defined and open-ended, applying control group approach or conducting protocol analysis won't be able provide clear base to assess students improvement. The
research group believes the life-long learning is key for any successful building designers, and any design alternative proposed by a designer represents a complicate internal process in balancing different aspects design information.

Meanwhile, the scientific computation technology and visualization tools have been constantly modified by the rapid advancement of computer calculation capability. In order to avoid wasting the project resource on debating and validating the method adopted in assessing students' performance. The research group mainly adopts direct observation and user feedback as the two main means to collect information on the effectiveness of proposed approach. Once the information is collected, discussion sessions are carried out among team members in order to justify the methodologies in running the pilot design projects and the specification in establishing required scientific computation infrastructure.

3 Establishment and Testing of Pedagogy

3.1 COMPUTATIONAL FLUID DYNAMICS (CFD)

In ARC5102, students applied Fluent software to study problems of ventilation and air quality. The case study focused on a public toilet in Lai Chi Kok park. This study was proposed by the Hong Kong Architectural Services Department (ASD). Students presented their analyses and design proposals at ASD headquarters on 24 March 2000.

We have developed a data translator from Fluent to OpenInventor format for visualizing CFD results in stereo virtual reality. We are also investigating the purchase of Ensight software for general-purpose visualization of CFD and other finite element analyses.

One of the major difficulties to implement CFD simulation into architecture curriculum is the extremely expensive software license fee. Long-term negotiation with the US and Beijing vendors to fight for a special arrangement for CUHK to have 99% academic discount for Fluent, Airpak & Gambit, the core technology for computational fluid dynamic (CFD) simulation. CFD is the core component for the building performance simulation and the key technology for the University’s strategic development in the Department of Architecture, March 2002.(The deal made CUHK becomes the biggest CFD software licenses holder among Hong Kong including all the commercial engineering firms, and any single departmental laboratory in Asia. The special arrangement is last for five years duration.)
3.2 DAYLIGHTING STUDY AND ANALYSIS

In ARC5102, students applied Radiance software in a comparative study of facade shading devices for public housing. For their case studies, they used the Hong Kong Housing Department’s “Harmony”, “New Cruciform”, and “Concord” block prototypes.

In ARC3110, students applied Radiance software to study inter-block shading in Hong Kong’s high-rise urban environment. We used data from a geographic information system (GIS) to create a digital model of the subject site, including neighboring streets and buildings. The students collaborated to design buildings for the site to make the best use of available sun and shadow for natural day lighting without excessive glare or heat gain.

3.3 ACOUSTICS

In ARC6020, students consulted on several occasions with Profs. Paul Chang, C. M. Chan, J. S. Kuang, and others in the Department of Civil Engineering at the Hong Kong University of Science and Technology (HKUST). Besides advising the students on their particular design projects, we also discussed issues for software and scientific visualization in structural design for architecture. Following these discussions, HKUST is preparing tutorial and demonstration material for their TBCAD software, which we plan to use for structural design in architecture in the next academic year.

We are collaborating with the Sheffield University to further develop our existing acoustic curriculum in three major areas, Urban Noise, Room Acoustics and Sound Absorption Material.

For the urban noise study, we are interested in the noise propagation in urban streets. Based on a comprehensive C++ program for simulating sound propagation in urban streets, a simplified computer tool has been developed in Excel using Visual Basic. Students can use the tool straight away without any training. The user-friendly interface allows students to change relevant parameters easily, and see the effect immediately. To ensure real-time output, the tool is based on relatively simple configurations, namely a single rectangular street with geometrically reflecting boundaries. The variables are mainly street geometry, façade absorption, and air absorption.

For the room acoustics study, we focused on the room acoustics simulation based on Radiosity. Based on the radiosity technique, a computer program has been developed for calculating sound propagation in rectangular enclosures. The program has been used to demonstrate the effectiveness of room geometry and surface materials on several important acoustic indices for room acoustics quality, including reverberation time, early decay time, sound distribution, and impulse response (where an echo can be ‘seen’). Also, based on a review of several acoustic simulation software, Raynoise has been purchased both in Chinese University of Hong Kong and Sheffield
University, and training has been organized. In both universities, the software has been intensively used in teaching at several levels and in some practical work.

For the sound absorption material study, the objective of this part of work was to help students to understand the physical principles of acoustic materials. A typical sound absorption material, perforated absorber, was chosen. The material can be made using transparent materials, which are particularly useful in Hong Kong. Based on theoretical work carried out by Kang and colleagues on micro-perforated panels and membranes, a simplified computer tool in Excel using Visual Basic has been developed. Students can use the tool straight away without any training. The user-friendly interface allows students to change relevant parameters easily, and see the change in absorption immediately. It is important to note that one layer to three layers of materials have been considered. This can help students to understand that with an existing material from market, they can greatly improve or adjust the properties through their own design.

3.4 STRUCTURES

In ARC6020, students consulted on several occasions with Profs. Paul Chang, C. M. Chan, J. S. Kuang, and others in the Department of Civil Engineering at the Hong Kong University of Science and Technology (HKUST). Besides advising the students on their particular design projects, we also discussed issues for software and scientific visualization in structural design for architecture. Following these discussions, HKUST is preparing tutorial and demonstration material for their TBCAD software, which we plan to use for structural design in architecture in the next academic year.

To support the TBCAD structural design system being developed at HKUST, we have purchased the ETABS™ analysis software (from Cyber Project Ltd.) that serves as its core. Meanwhile, HKUST is looking into separating their design synthesizer and post-processor modules from the ETABS™ core to make TBCAD more “portable”. The commercial ETABS™ core requires a license fee, but HKUST has offered to share their design synthesizer and post-processor modules with us, free of charge. During a recent coordination meeting, Prof. Paul Chang also agreed to allocate resources to develop a user manual and example case files for the TBCAD system.

3.5 ENERGY

We are testing the Building Design Advisor (BDA) software from Lawrence Berkeley Laboratories (LBL). BDA requires an accurate empirical database of weather conditions for the locality of the building. The standard distribution includes data for mostly US cities that are not good matches for
Hong Kong’s dense urban tropical environment. Therefore, we have obtained weather data from the Hong Kong Observatory and reformatted it for use as a BDA climate database. We have also had to reconvert this weather database in upgrading to the latest release of the BDA software. Dr. Kostas Papamichael, the team leader of the BDA project, has offered to host a visitor from CUHK to LBL this autumn for another round of consultation and training.

3.6 SCIENTIFIC VISUALIZATION IN VIRTUAL REALITY

We inquired into purchasing Ensight™ software for visualizing building performance simulations in stereo virtual reality. Although former staff in our department had used this software several years ago, the vendor has now informed us that they no longer export to China. Since the license fees for Ensight™ would have been substantial in any case, we have decided instead to develop our own in-house software. This frees us not only from annual license fees, but also from restrictions on the software’s use (for example, in applied research versus classroom teaching).

We are continuing to develop this software. The current version imports numeric data from Fluent™ release 4.5 universal files and particle track history files, and constructs boundaries, vector fields, animated particle flows, and isosurfaces for various fluid properties. We’re now beginning work to import data in Patran or AVS format, to support Fluent™ release 5.5, as well as Raynoise and other analysis programs.

3.7 INTERNET

We have established a hypermail server to facilitate web-based design collaboration. The server allows participants to post text and graphics through e-mail to a web page for group discussion. It eliminates the need to send e-mail to multiple recipients, and avoids overflowing participants’ mailboxes with large graphics attachments. Posted messages appear on the group’s web page without the need for continual webmaster intervention.

4. Conclusion

To conclude, the scientific computation technology and visualization tools have been constantly modified by the rapid advancement of computer calculation capability. In order to avoid wasting the project resource on debating and validating the method adopted in assessing students’ performance. The research group mainly adopts direct observation and user feedback as the two main means to collect information on the effectiveness of proposed approach. Once the information is collected, discussion sessions
are carried out among team members in order to justify the methodologies in running the pilot design projects and the specification in establishing required scientific computation infrastructure.

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