CDIO APPROACH FOR DEVELOPMENT OF TEMPERATURE RISE MONITORING SYSTEM

Tao Nengfu 1, Li Xiaodong 2, Lu Jinping 3

1 School of Architecture and the Built Environment, Singapore Polytechnic
2 Advanced Materials Technology Centre, Singapore Polytechnic
3 Admaterials Technologies Pte Ltd, Singapore

ABSTRACT

A Research and Development (R&D) project sponsored by both the Building Construction Authority (BCA), Singapore and Admaterials Technologies Pte Ltd for the development of an Adiabatic Temperature Rise (ATR) testing system to replace on-site mock-up tests for preventing cracks of concrete, improving concrete durability and sustainability, and enhancing construction productivity was successfully completed last year. Conceiving, Designing, Implementing, and Operating (CDIO) approach was used for the development of the system by a team consisting of two academic staffs, two groups of Final Year Project (FYP) students and an industry collaborator. This system has won the Singapore Polytechnic R&D Award 2018 and Singapore Ministry of Education Innergy Award 2018. This paper describes in detail how the team used CDIO standards especially standards 5, 6, 7 and 8 as a guideline to conceive, design, implement, and operate the system. It also illustrates in detail how the final year project (FYP) students used Singapore Polytechnic's Advanced Materials Technology Research Centre as a learning workspace for achieving pre-defined learning outcomes. In future a capstone project, which requests students to conceive and design a "recipe" and test concrete samples cast using the "recipe" by the ATR system for checking its effectiveness, will be developed for module "Structural Inspection & Repair" for students to do active and real time experiential learning of mass site concreting in Laboratory environment. Feedback was collected from the two groups of students after they had completed their FYPs. The very positive feedback shows that students have developed strong competency in obtaining disciplinary and cross-disciplinary knowledge and skills in reasoning through active and project-based learning, collaborative and coordinative team work spirit, and strong skills in report writing and presentation etc., which are required by CDIO syllabus.

KEYWORDS

CDIO Approach, Adiabatic Temperature Rise (ATR) Monitoring System, Workspace Learning, Self-Directed Active Learning, Standards: 5, 6, 7, 8

INTRODUCTION

The Conceiving, Designing, Implementing, and Operating (CDIO), designed to deliver the knowledge and skills needed by industry, is a framework of engineering education curricula for developing next-generation engineers. CDIO provides educators with an important platform in engineering education to establish a new way of conceptualizing teaching and learning, which emphasizes engineering fundamentals as well as all the aspects and skills needed to enable a student's future career. The goals of the CDIO approach are to educate students who are able to (Edward Crawley et al, 2007):

- Master a deeper working knowledge of the technical fundamentals
- Lead in the creation and operation of new products, processes, and systems
- Understand the importance and strategic impact of research and technological development on society

The CDIO's 12 Standards of are very critical to both the curriculum planning and the extensive use of Project-Based Learning for students (Tao N.F., Yoong Y.S., Tan P.S. 2009), especially for those who are doing their Final Year Projects (FYPs) which are part of on-going Research & Development (R&D) projects and use laboratories very intensively will encounter repeated cycles of designing-building-operating systems. CDIO approach for Project-Based Learning has been shown to increase the acquisition of both deeper technical knowledge and nontechnical skills, such as teamwork and communication, and the benefit of which is to retain more students in choosing engineering as their course of study. Interestingly, it has been demonstrated that exposure to Project-Based Learning in the first and second year preferentially retains women (and potentially minorities) in engineering, and exposure in the junior and senior years influences the career choices of students away from non-engineering paths, back to careers in engineering (Edward Crawley et al, 2010).

The successful completion of a R&D project titled Development of Adiabatic Temperature Rise (ATR) Testing System with a duration of 2 years from the beginning of 2016 to the end of 2017 and sponsored by both the Building Construction Authority (BCA), Singapore and Admaterials Technologies Pte Ltd for replacing existing way of on-site mock-up tests and preventing cracks of concrete, improving concrete durability and sustainability, and enhancing construction productivity with involvement of two groups of FYP students using CDIO approach specifically CDIO standards 5, 6, 7 and 8 is a valuable experience which is worth of being shared here.

The project won Singapore Polytechnic R&D Award 2018 and Singapore Ministry of Education Innergy Award 2018. Looking forward, the future plan is to develop a capstone project, which requests students to conceive and design a "recipe" for mass concreting and check its effectiveness by testing concrete samples cast using the "recipe" by the ATR system for module "Structural Inspection and Repair" for students to do active and real time experiential learning of mass site concreting in Laboratory environment. Survey questions were designed and feedback was collected from the two groups of FYP students after they had completed their FYPs. The very positive feedback shows that students have developed strong competency in obtaining disciplinary and cross-disciplinary knowledge and skills in reasoning through active and project-based learning, collaborative and coordinative team work spirit, and strong skills in report writing and presentation.

THE URGENT NEED OF ATR SYSTEM FOR CONSTRUCTION INDUSTRY

The hydration reaction of cement during the course of construction of concrete structures which will develop a large amount of heat with an increase in the concrete temperature. At high temperature (>70°C), ettringite transforms to monosulphate at very early stage of hydration and once the concrete has been hardened, under permanently or intermittently wet condition, monosulphate converts to ettrintgite (Yang R., Lawrence C.D., Lynsdale C.J., Sharp J.H., 1999), which takes up more space than monosulphate from which it forms, and thus causing cracking in concrete. This problem is particularly important in mass concrete structure like pile caps, deep beams, bridge piers and raft foundations where heat dispersions are very small and core temperature can be very high (Yang R. et al, 1996).

In the current practice in the construction industry, mock up tests are almost always required on high profile and commercial projects by the architect, engineer, or owner, before the commencement of construction work. Collecting, monitoring, recording, and responding to the temperature of the mock-ups along with weather data from the construction site, will allow the construction team to minimize the risk of problems. However, the current method of mock up test takes around two weeks which will delay the construction schedule. Furthermore, the test will increase both the cost of manpower and materials, and in addition, the removal and disposal of the mock-ups up debris of up to 200 m^3 after test will be a problem.

To overcome the above problems, it is necessary to develop a new system for accurate testing and monitoring the concrete temperature, specifically the temperature rise in concrete. Hence a Research and Development (R&D) project was proposed by a team consisting of two academic staffs, two groups of FYP students and an industry collaborator. The project was approved and sponsored by both the BCA, Singapore and Admaterials Technologies Pte Ltd for the development of an ATR testing system to replace current test method.

CDIO APPROACH FOR THE DEVELOPMENT OF ATR SYSTEM

The aim of developing ATR monitoring system is to replace current way of on-site mock-up test and monitor temperature rise in the concrete being used. A trial mixture of the concrete of interest is prepared in lab and its temperature rise is monitored when hydrated under adiabatic conditions in a laboratory environment in advance. Maximum allowable concrete temperatures and temperature differences are measured to ensure that proper planning occurs prior to concrete placement. The term adiabatic refers to a process occurring without any heat exchange between the concrete sample and the surroundings. That means concrete sample cannot suffer any heat loss/gain to/from surroundings theoretically this can be realized by creating a surroundings and keeping its temperature always equal to that of concrete sample.

To achieve the above aim, the ATR system was developed by following CDIO’s Conceiving, Designing, Implementing, and Operating sequence of four stages over a period of 2 years with the involvement of two groups of FYP students into the project. The 1st FYP group consisting of 4 students was allocated and involved in conceiving the system specifications and designing the whole system according to the specifications during the academic year 2016. System fabrication (implementing stage) was done by an external professional fabricator. The intended learning outcomes for the 1st group of FYP students were: a) applying disciplinary and cross-disciplinary knowledge and online research to conceive and design a system for monitoring temperature rise precisely in mass concreting; b) teamwork and communication; and c) report writing and presentation. The 2nd FYP group consisting of 3 students was allocated for involving in Operating stage by making lots of concrete samples for testing to monitor adiabatic temperature rise in these concrete samples in order to check and validate system’s reliability, repeatability and durability during the academic year 2017. The intended learning outcomes for the 2nd group of FYP students were: a) reasonableness of designing concrete-mix for making concrete samples; b) skills and knowledge of the procedures for making concrete samples to the standards required by local authority; c) teamwork and communication; and d) report writing and presentation.

CDIO APPROACH USED AT DIFFERENT STAGE OF DEVELOPMENT FOR THE INTENDED LERNING OUTCOMES

Project Brief

Before the start of the project, students were briefed to understand the technical requirements of the system, e.g. homogeneity of water, i.e. the water temperature between any two positions in a tank to be designed should not be larger than 0.5°C, and come out specifications for concept design. Students were also briefed the learning activities and tasks to be completed by them for their FYPs. Safety requirements of using Advanced Materials Technology Research Centre's laboratory for tests were also briefed by the technician.

Conceiving Stage

At conceiving stage, students were required to come up with specifications for concept design. A range of activities for active and self-directed learning in classrooms, library and laboratories were arranged for the FYP students to complete. Students were required to do intensive reading of online materials, magazines and books as well as research activities for a write-up of literature review to summarize all the existing systems which can perform similar functions to the proposed ATR system that they were going to develop. Advantages and disadvantages of those existing systems must be listed out, and at the same time, a table showing and comparing all the available functions of those systems must also be provided. At this stage, team work and collaborative learning were strongly encouraged. Peer review of team work was conducted at this stage. Detailed specifications for ATR are shown follows:

1) Single tank design and fabrication with size of 500mm × 500mm × 700mm Height, to provide up to 125 litres of water.
2) Tank: stainless steel 304, 1.5mm thickness, cover, 4 swivel castor wheels, 2 wheels with brakes, 2 manual SS valves.
3) Rockwool insulation with thickness of 2” is placed between the tank and cover
4) Estimated fresh concrete sample volume 20-25 litres (diameter 300 mm, height 300 mm)
5) Electrical accessories and heater design and fabrication, should be able to raise the temperature of water from room temperature 25°C to 95°C, 8 pcs thermocouples, 4 pcs heating elements.
6) Estimation of time needed will be 9 hours for 125 litres of water and 3.5 hours with 50 litres of water from 25°C to 85°C. Ramp rate for water will be ~0.3°C per minute.
7) Circulation (Bubbling pipe and pump or stirrer) used for water homogeneity.
8) Loan control, measurement and data logger system with software program from vendor.
9) Evaluate the homogeneity of water temperature in the tank using 9-point Thermocouple measurement during ramping and during steady-state at 85°C. Homogeneity of water in tank should be within 0.5°C. Repeat experiment with 50 litres, 75 litres, 100 litres and 125 litres of water.
10) Evaluate the temperature homogeneity within the tank during temperature ramp-up & at plateau/steady-state. Homogeneity of water in tank should be within 0.5°C.

Designing Stage

At this stage, students was required to design an ATR system according to the specifications that they came up at conceiving stage. To achieve this aim, FYP students were required to discuss with other students and faculty staff members from School of Mechanical Engineering, School of Electrical and Electronic Engineering, School of Design and School of Info Communication for acquiring cross-disciplinary knowledge on design of system portability, mechanical, electrical and electronic parts, and software for system control, etc. In addition, team work and communication skills were developed through these activities. A few designs were come out by the students for selection. 2D drawings and 3D models were generated using software AutoCAD 2018 and Revit 2018 in computer laboratories according to the specifications. After brainstorming, discussion and comparison, the design shown in Figure 1 and Figure *2* were chosen for fabrication.

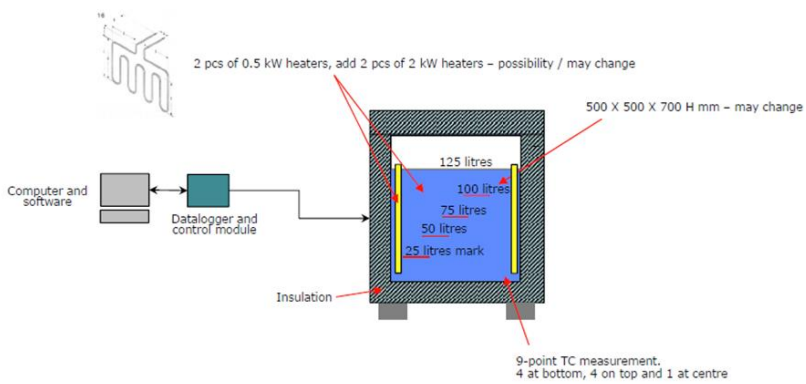


Figure 1. Water tank design

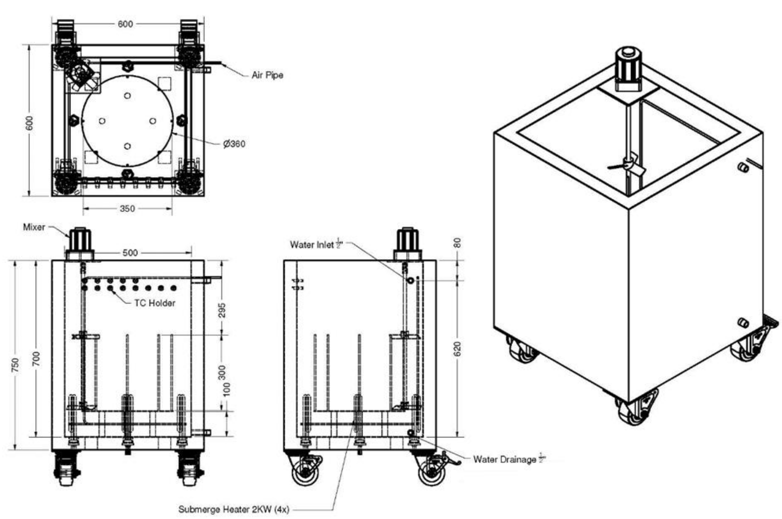


Figure 2. The schematic diagram of the water tank

Implementing Stage

Fabrication of the system and development of the computer software were done by an external fabricator and a software developer respectively according to design drawings and flowcharts provided. Figure *3*Figure *4*Figure *5* shows the system after fabrication. Students were required to play a coordination role to liaise with the external fabricator and software developer for any queries. CDIO Standards 5, 6 and 7 were used as guidelines for planning the learning activities of students.

Figure 3. Photo of the water tank (left), control panel (right)

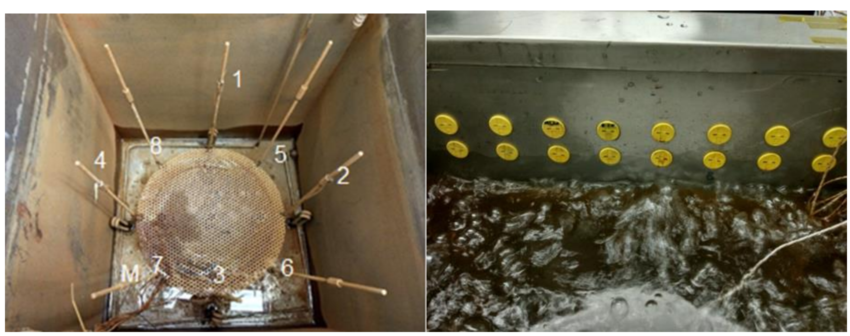


Figure 4. Internal fixture (left) and the internal connecter for the thermocouples (right)

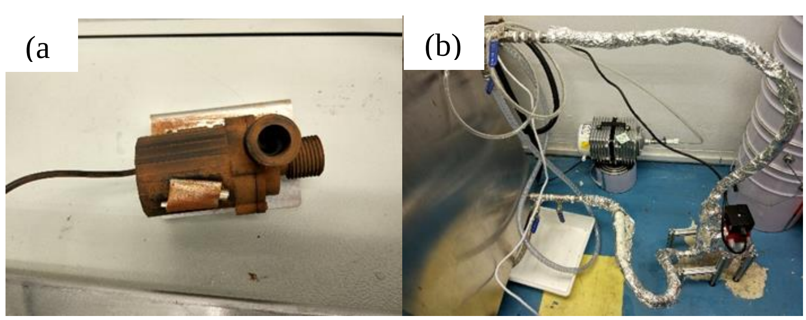


Figure 5. Uniformity improvement of water tank: (a) internal pump, (b) external pump

Operating Stage

At Operating Stage, students were required to make many concrete samples for tests using the fabricated system to monitor adiabatic temperature rise in these concrete samples in order to check and validate system’s reliability, repeatability and durability. The 2^{nd} group of FYP students performed these activities during the academic year 2017. At this stage students were required to design many concrete mixes. Table *1* shows an example of a design concrete mix. Concrete samples were then made according to the design mixes. Figure *6* shows two samples made by the students. Tests of samples are shown in Figure *7*a. Students were required to collect testing data and process the data collected for the purpose of checking and validating the system as shown in Figure *8* to prove that the design and fabrication of the system is reliable, repeatable and durable.

Table 1. Concrete Mix-Design

Concrete composition	Mass (kg)
Cement	10
Water	4.2
Sand	19
Coarse aggregates	25
Total	58.2

Figure 6. 20L Concrete sample for testing (before (left) and after (right) covering)

As seen from Figure 8 (a), the temperature rise of the four mixes was almost the same. It can thus be concluded that the repeatability of the system is good. The similar rates of temperature change of the four mixes (Figure 8(b)) further indicated the good repeatability of the system. For all the mixes used, the difference in adiabatic temperature rise and peak rate of temperature change were lower than 1.0 °C and 0.9 °C, respectively. Table 2 summarizes the results of the repeatability tests of the system (Li Xiaodong, Tao Nengfu, Huang Hai, Lu Jinping, 2017).

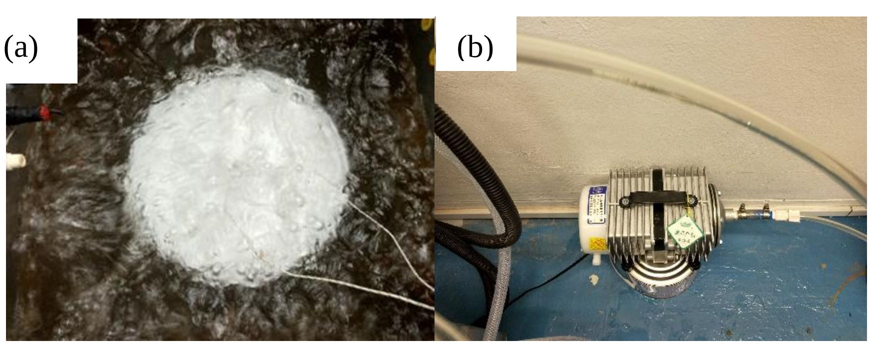
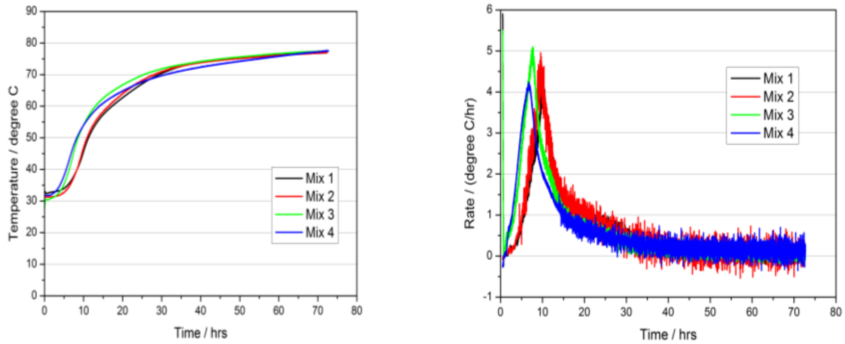


Figure 7. Concrete test setup (a) and compressed air pump (b)



(a) (b)

Figure 8. Temperature rise of concrete for four mixes (a) and rate of temperature change of concrete for four mixes (b)

Table 2. Summary of test results on repeatability

Mix	1	2	3	4	Max Difference
Adiabatic Temp Rise (°C)	41.10	41.50	42.10	41.50	1.00
Peak Rate (°C/hr)	4.02	4.43	4.92	4.22	0.90

Survey of Student Learning Experience

The purpose of conducting survey is to check the intended learning outcomes of the two groups of FYP students through their FYPs. In addition, considering that the 1st group of FYP students involved in conceiving, designing and implementing of the ATR system and the 2nd group of FYP students involved only in operating of the system, therefore two sets of survey questions for the 1st and 2nd FYP group of students were designed respectively. Except Q5, Q1 to Q4 request students to choose a score from 1 (worst) to 5 (best) for an indication of their satisfactory level. Table 3 shows the details of the survey questions.

Table 3. Survey Questions

Set 1 (For FYP Group 1 Students)	Set 2 (For FYP Group 2 Students)
Q1: The intensive reading and online research for literature review on the ATR system in what score builds up your capability in conceiving a system and gaining of new knowledge?	Q1: In regard with design concrete-mix for making samples, what score will you be giving for the plan and the way arranged for you in obtaining the disciplinary knowledge?
Q2: At design stage, what score will you be giving for the design skills that you have developed using the iterative design approach as well as the way of seeking consultancy from staff and students from other schools?	Q2: In regard with making concrete samples as well as testing them using the ATR system, what score will you be giving for the learning environment, e.g. the lab space, the small meeting room and the study room provided in terms of conducive learning?
Q3: At the checking and validating stage for the system, what score will you be giving for building up your competency in communicating with industry partners and suppliers?	Q3: In regard with data collecting and analysis of the collected data, what score will you be giving for building up your capability in manipulating, applying, analyzing and evaluating scientific data sets and discovering new knowledge?

Q4: Overall what score will you be giving for the self-directed learning experience that you have gone through this FYP?	Q4: Overall what score will you be giving for the active learning experience that you have gone through this FYP?
Q5: Any other comments on what you have learnt through and benefited from involving in this FYP.	Q5: Any other comments on what you have learnt through and benefited from involving in this FYP.

The survey questions were sent to the two groups of FYP students via emails after they had completed their FYPs in Academic Year 2016 and 2017 respectively and the survey results are shown in Figure *9*. By and large the scores for the two sets of questions given by the students are very high which demonstrates the successfulness of using CDIO approach for their FYPs. In particular, for FYP group 1 students, they felt that they had better improvement in communication skills. However for FYP group 2 students, they felt that they had great improvement in building up their capability in collecting and analyzing data.

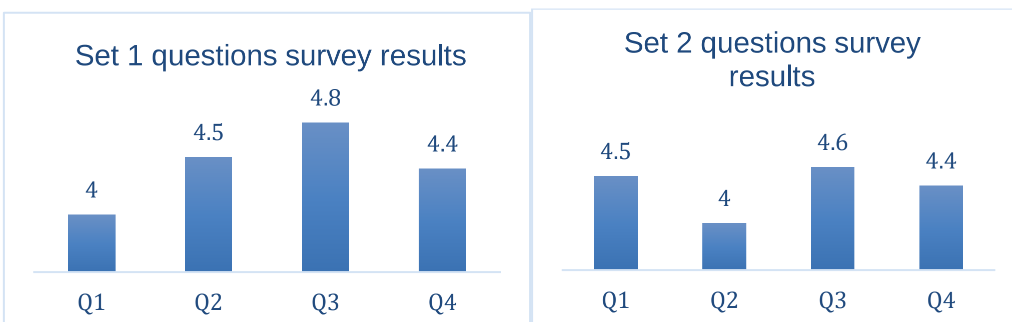


Figure 9. Survey results for set 1 and 2 questions for the 1st and 2nd FYP group of students

As for Q5, comments were collected from the two groups of FYP students. Overall their feedback was very positive, which demonstrates that students have developed strong competency in obtaining disciplinary and cross-disciplinary knowledge and skills in reasoning through active and project-based learning, collaborative and coordinative team work spirit, and strong skills in report writing and presentation etc., which are required by CDIO syllabus.

FUTURE WORK

ATR system has been successfully developed and can be used for tests of new and green concrete materials. Looking forward, as a 1st trial of using the ATR system for student hands-on learning activities, a capstone project, which requests students to conceive and design a “recipe” and test concrete samples cast using the “recipe” by the ATR system for checking its effectiveness, will be developed for module “Structural Inspection & Repair” for students to do active and real time experiential learning of mass site concreting in Laboratory environment. In long term, more capstone projects using the ATR system for modules such as “Reinforced Concrete Design” and “Construction Materials” can be developed for students to do their study under CDIO framework.

CONCLUSIONS

This paper illustrates in detail how FYP students involved in a R & D project using CDIO approach and successfully developed an ATR system to replace the current way of test for the construction industry.

The intended learning outcomes using CDIO approach were checked by survey careful designed questions, and the very positive survey results show that students have developed strong competency in obtaining disciplinary and cross-disciplinary knowledge and skills in reasoning through active and project-based learning, strong teamwork spirit and skills in report writing and presentation.

In the future, a capstone project will be developed for student to do active and real time experiential learning of mass site concreting in Laboratory environment.

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BIOGRAPHICAL INFORMATION

Dr Tao Nengfu is a senior lecturer in School of Architecture and the Built Environment, Singapore Polytechnic. His current scholarly interests are Computer Science, Structural Engineering, Soil Dynamics and Earthquake Engineering.

Dr Li Xiaodong is a research scientist in Advanced Materials Technology Centre, Singapore Polytechnic. His current research interests are building materials and materials recycling.

Mr. Lu Jinping is Managing Director of Admaterials Technologies Pte Ltd, a testing, certification and consultancy company in Singapore. His current research interests are development and test of new building materials.

Corresponding author

Dr Tao Nengfu
School of Architecture and the Built Environment
Singapore Polytechnic
500 Dover Road, Singapore 139651
cnftao@sp.edu.sg