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Adoption of CDIO elements in the final year civil engineering design project

Peng Lin, Yingzi Wang, Guangjing Xiong, Weikun Wu & Huiliang Huang

Shantou University
Shantou, People's Republic of China

ABSTRACT: The principles of *Conceive – Design – Implement – Operate* (CDIO) are being adopted in the civil engineering programme at Shantou University in Shantou, People's Republic of China, where student design teams are now involved in their final year design project. In carrying out the project, students were encouraged to develop and practice teamwork skills, practical engineering and the application of integrated disciplinary and non-technical knowledge, all of which are called for in the CDIO Standards. The process and features of the project are presented in order to illustrate the adoption of CDIO elements. Problems, conclusions and suggestions are also discussed.

INTRODUCTION

In 2005, the College of Engineering at Shantou University in Shantou, People's Republic of China, adopted the *Conceive – Design – Implement – Operate* (CDIO) educational framework. The principles and standards of CDIO are being used to design and implement new curricula and course content in all the University's engineering programmes [1]. Most of the CDIO applications are in the areas of mechanical, aeronautical and electrical engineering programmes [2]. Therefore, most of the reference materials in CDIO were developed from those disciplines [3][4].

However, little material is available for civil engineering. The main challenge for the civil engineering programme is the design and implementation of a curriculum based on the CDIO Syllabus and Standards. The proposed approach was the adoption of CDIO elements in a few selected courses, while redesigning the curriculum. One of the selected courses was the final year civil engineering design project.

Although final year projects in the civil engineering programme usually cover large and complex systems, such as metro or highway systems, students in the past were required to carry out the project individually, rather than in teams, focusing on a single engineering problem, such as the embankment problem of a highway system or a tunnel problem for a metro system. However, student design teams were used for one of this year's design project, namely the *Shantou-based metro system project*, as an application of CDIO elements and standards.

Two student teams were formed, each of which consisted of four students. They were required to complete the project in 14 weeks. One team of four students focused on the general plan of metro system and environmental design, including the scale control of the metro system, the selection of the metro lines, the arrangement of station location and the architectural design of different themed stations. The other team of four students addressed the construction of the underground structures, including the excavation of running tunnels, structure design and construction of metro stations.

In carrying out team-based projects, students were encouraged to develop and practice both technical knowledge and non-technical skills, such as teamwork and communication, which are called for in the CDIO Standards. Because the students of the civil engineering graduating class had never had any courses with CDIO concepts, the adoption of CDIO in the new project was a challenge both for students and professors. The experience will be useful for developing and implementing the new civil engineering curriculum based on CDIO Standards.

PROCESSES AND OUTCOMES OF THE *SHANTOU-BASED METRO SYSTEM PROJECT*

In the Shantou-based metro system project, eight students work together to complete it over 14 weeks. The programme of the project is outlined in Figure 1, which shows that the five parts of the project are systematic and interrelated, but also relatively independent.

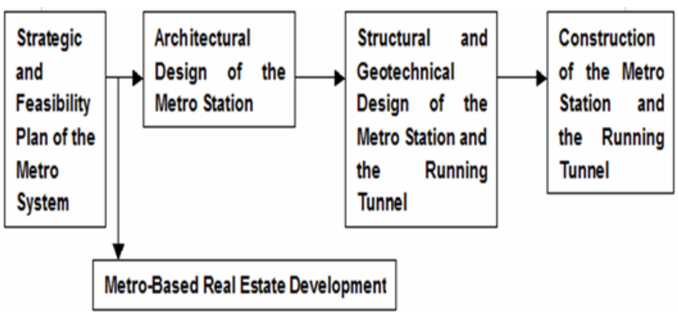

Figure 1**:** Programme of the metro system project.

Students worked in their assigned parts, called sub-projects, in order to finalise the whole project. The title of the whole project is *The Plan and Design of the Shantou Metro System Project*. The final compositions of the sub-project, written by students, were also used for their bachelor degree theses.

In the general plan of the metro system, students undertook detailed analyses of Shantou's population status, economic development and current traffic problems. The strategic and feasibility plan of the metro system would be the final outcome, as well as the selection of the metro line and the arrangement of the metro station location. After working for 14 weeks, a sub-project, with title of *General Plan* was compiled by one student. This involved related parts of the general plan of the metro system project, such as the background of the plan, development goals, advice from financing, advice regarding construction by stages, a map of the metro lines and the arrangement of metro station locations, etc.

In the architectural design of metro stations, students considered the factors of the environment, architectural function and aesthetics in order to give the architectural scheme for different themed stations. A series of dimensional data of the building structure were also provided for further structural and geotechnical design.

After working for 14 weeks, a sub-project with title of *Architectural Design of a Metro Station Building and Entrance to the Metro Station*" was undertaken by a student. This involved architectural designs of a transfer station and an interzone station with a tri-arch shape, the architectural designs of several entrances of metro stations. Figure 2 shows one of the architectural designs of the metro transfer station. Figure 3 shows the architectural design of tri-arch station.

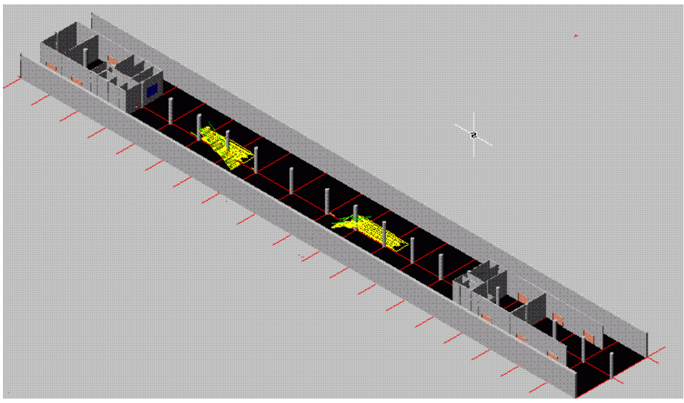

Figure 2: Architectural design of the metro station.

According to the relevant architectural scheme of metro stations and running tunnels, students carried out a series of detailed computations in the structural and geotechnical design. This covered the underground structure of the metro station, the retaining structure of the excavation and the lining structure of the running tunnel, with numerous drawings to support them.

After working for 14 weeks, two sub-projects with titles of *The Structural Design of Metro station and Excavation Engineering* and *The Geotechnical Design of a Shield Tunnel and Tri-Arch Station* were compiled by two students. Figure 4 shows the 3D finite element (FEM) analysis of the metro station's retaining structure. Figure 5 shows a structural analysis of the tri-arch station.

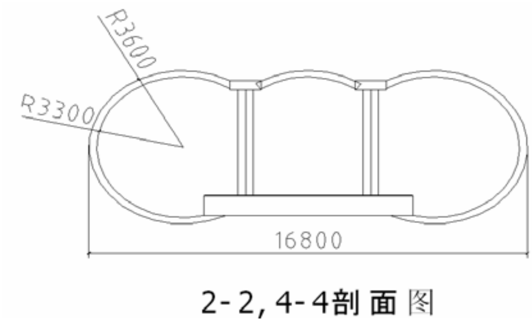

Figure 3: Architectural design of the tri-arch station.

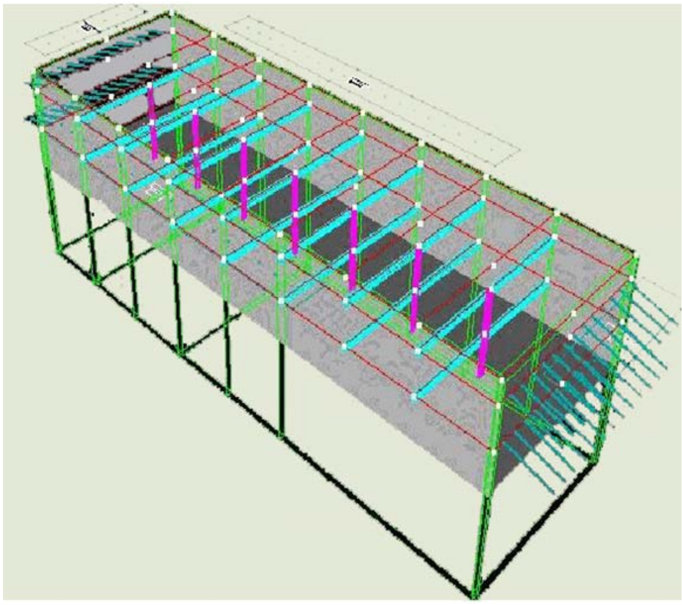

Figure 4: 3D FEM analysis of the retaining structure of the metro station.

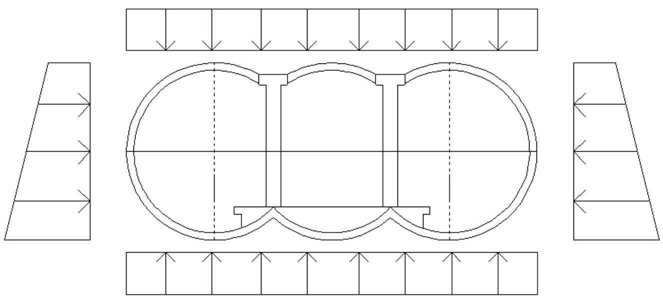

Figure 5: Structural analysis of the tri-arch station.

The real estate element was an interesting and attractive project. Students were given a block of land located beside the future metro station. According to the market analysis, they developed the land into a so-called *house garden*. They presented a series of design schemes to support their sales and advertisement project, including the building arrangement, the departmental style and landscape design in the housing district. After working on this for 14 weeks, a sub-project with title of *The Development of Real Estate along the Metro Line* was completed by two students. Figure 6 shows part of a layout of the housing district. Figure 7 shows the arrangement of the building blocks and landscape of the housing district.

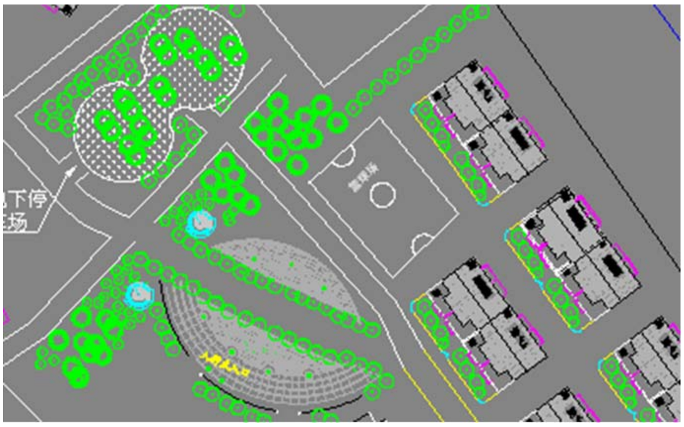

Figure 6**:** Part of the layout of the housing district.

Figure 7: Arrangement of the building blocks and landscape of the housing district.

The final part was the construction project of the metro station and the running tunnel. The expected results would be the construction organisation scheme and the relevant bid contract. After working on this for 14 weeks, two sub-projects with titles of *Construction of a Metro Station* and *Excavation of a Shield Tunnel and Construction of the Tri-arch Station* were completed by two students. Regular stations were built using a cut-and-cover technique, while the running tunnel and the tri-arch station were built utilising the closed technique, namely the shield machine method.

As described above, in carrying out the project, students are required to know and engage in scheming, planning, designing and construction. The whole project is assigned to be as similar as possible to practical engineering so that team members are encouraged to simulate the roles found in the real civil engineering world, namely investors, architects, structural and geotechnical consultants and construction contractors. The interpretation of their roles includes conflict, interaction and compromises at different phases of the project. Students' skills regarding creation, teamwork, the application of integrated knowledge and interpersonal dynamics will be significantly improved during the project.

TEAMWORK IN THE PROJECT

In the past, students were required to carry out the final year civil engineering project individually, rather than in teams, emphasising completing the project independently. This resulted in a lack of practical skills in students, like communication and interpersonal dynamics. With the CDIO principles being adopted in the civil engineering programme, student design teams were, therefore, used for this metro system project. In the project, team members were encouraged to work together and engage in adequate communication and discussions to guarantee the fulfilment of the task.

Although members were designated individual tasks, all members were involved in some important design schemes, such as the selection of the metro lines, the arrangement of the metro station location and the investment control of the metro system. In team members' individual projects, students were required to present their own schemes in meetings with all members and to accept others' opinions and revise the scheme accordingly.

Each part of the metro system was so relevant that it needed effective communication for further work. For example, the dimensional data of the structure attained in the architectural scheme should be available for structural and geotechnical design. The construction process also relied mainly on the results of structural and geotechnical design, and vice versa. Non-preassigning datum before design, each member had to communicate thoroughly and effectively so as to avoid any wrongdoing in the project.

After training in the project, team members felt free to openly present their plans and express their views. Teamwork helped them to complete such a large and complex project in only 14 weeks.

SIMULATION OF PRACTICAL ENGINEERING IN THE PROJECT

The metro system project was designed to be as close as possible to practical engineering so that team members were encouraged to simulate the roles found in the real engineering world, namely investors, architects, consultants and contractors. When discussing the whole project, they acted as a team. However, in their individual projects, students had their own positions and profit concerns.

During the project, earning personal profit, coordinating with other team members and compromising raised many problems in interpreting their roles. For example, students who were carrying out the strategic and feasibility plan of the metro system took on the roles of investors. They had the final influence on determining the selection of the metro station style, the construction method of the running tunnel and so on. No matter how magnificent and attractive the architect's scheme was, they forced the designer to choose the *moderate one*, instead of the original splendid design in order to reduce costs and remain within the budget.

Such levels of conflict and compromise were often seen during the project, just as they are in the real engineering world. Team members' skills in presenting personal views, persuading other project partners and synthesising various opinions improved significantly. Through their efforts to be accepted by other members, they enhanced their self-worth and confidence, which would be a great help to them when entering the real engineering world.

THE APPLICATION OF INTEGRATED KNOWLEDGE IN THE PROJECT

The Application of Disciplinary Knowledge in the Project

The metro system project provided team members with the opportunity to integrate their four years of knowledge in the discipline, as well as their design and project skills. However, this was not enough. Additional knowledge was inevitably needed in order to meet the demands of the project; therefore, members were required to attain relevant knowledge through self-learning.

For instance, in the geotechnical design of tunnel excavation, members had to search for additional knowledge through self-learning and the Internet so as to meet the demands of the project, such as shielding methods during tunnel excavation and the special structure of the tri-arch spans of the metro station, in addition to traditional curriculum knowledge like engineering geology, soil mechanics, ground improvement and excavation engineering.

In doing so, students extended their basic disciplinary knowledge to incorporate relevant project and design fields. It is envisaged that this learning and working method will help them to become effective engineers and bring them lasting benefits.

The Application of Non-Technical Knowledge in the Project

In the project, attention was paid to increasing students' economic knowledge and market consciousness, as well as developing their potential skills in product promotion. For example, in the metro-based real estate project, members were required to put forth a feasibility plan after enough market research. They presented a series of design schemes in order to support their sales and advertisement project, including the building arrangement, style and landscape design in the district. The price and building-up of the brand, in terms of the sales and advertisement scheme, was the expression of their potential economic skills.

In the construction project, students focused on the concept of cost and evaluated their engineering expenditure in order to submit a bid contract according to practical engineering.

Although economic knowledge goes beyond students' disciplinary knowledge, they are introduced to the potential skill of costing, thereby enhancing students' competences in the engineering world.

PROBLEMS ENCOUNTERED IN THE PROJECT

Because team members previously never had any courses covering CDIO concepts, there were some problems encountered during the project. There were difficulties in the application of non-technical knowledge. For example, when undertaking the strategic and feasibility plan of the metro system, students felt that it was difficult to tackle economic data, such as population status, market research, business networks and so on. It took quite a bit of time to determine where to find this information and how to utilise it.

The other problem was that, at the beginning, students were not accustomed to team-based projects. They seldom gathered together to have discussions. The early discussions were also unsatisfactory due to the lack of system and routine, and little help was provided in solving problems. Although students' dialogue improved quite a lot as the project progressed, they took too much time and this greatly impacted the project's schedule. This shows that it is important to have courses or projects with CDIO elements as early as possible in the civil engineering programmes.

CONCLUSION

As part of the CDIO implementation plan, the final year civil engineering design project, the metro system project, introduced some significant CDIO concepts and standards. In carrying out the project, students were encouraged to develop and practice teamwork skills, simulate practical engineering, and apply integrated disciplinary and non-technical knowledge, all of which are called for in the CDIO Standards.

The result is that it was appropriate to adopt CDIO elements in the metro system project. It provided students with the opportunity to practice engineering problem solving and to improve their professional, personal and interpersonal skills. Future work should include an adjustment of the tasks' difficulty with students' abilities and an invitation to practical engineers to be supervisors. In order to enhance students' non-disciplinary skills, it is strongly recommended that non-civil engineering students, such as students from the commercial college, be invited to join the project.

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