A CDIO APPROACH TO TEACH SUSTAINABILITY IN ARCHITECTURE

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ABSTRACT

The CDIO initiative, an educational framework that comprises 12 standards for evaluating and reforming engineering programs. The framework has become a guiding principle for program leaders to reform and evaluate curriculums, create benchmarks, and align learning goals with worldwide application, making it a framework for continuous improvement. The School of Architecture and the Built Environment (ABE) at Singapore Polytechnic adopted the CDIO framework to guide non-engineering diploma programs towards continuous improvement. A professional development course was designed by the ABE Teaching & Learning (T&L) unit to coach program leaders on evaluating their programs. Their initial task after completing part 1 coaching was to map their diploma program to CDIO standards.

This paper focuses on how one of the non-engineering programs, a three-year Diploma in Architecture from the Singapore Polytechnic, maps itself to CDIO (Conceive, Design Implement, Operate) standards, specifically CDIO 3.0, with a specific emphasis on sustainability. This paper first discusses how sustainability knowledge has been incorporated in the program (vertical integration), levelling up progressively over the three years of the program. It then describes the mapping of CDIO standards in the program via three threads: 1) the process of architectural practice; 2) Skills framework for the Architecture sector; 3) Green Mark 2021. The program addresses 10 out of the 17 United Nations Sustainable Development Goals (SDGs) and implements them through a horizontal integrated year two curriculum. The selected course, Design Studio I (Architecture) (DS1(A)) is centered on an integrated design project that provides students with the opportunities to apply and contextualize sustainability knowledge, skills, and attitudes with technological advances. This paper also presents the findings from students' feedback and learning reflections of DS1(A) as well as the teaching team's perspectives. It then concludes with considerations of incorporating sustainability and the challenges of teaching sustainability in DS1(A).

KEYWORDS

Sustainability development, design-implement, architecture, non-engineering, CDIO standard 1, 2, 3 and 5 and CDIO optional standard 1.

BACKGROUND

CDIO has been the anchoring curriculum framework for engineering courses in the Singapore Polytechnic since 2004. In 2021, the School of Architecture and Built Environment (ABE) Teaching and Learning Unit (TLU) launched an enhanced professional development program (CDIO standard 10) for program leads to strengthen their current program curriculum as well as teaching and learning approach. It also aims to widen its reach to non-engineering

programs. The program leads of six diplomas in ABE were trained to map their curriculum onto CDIO 12 standards, focusing on making sustainability more visible to teaching staff and students and strengthening it using the CDIO approach. Out of these six programs, one is engineering and five are non-engineering. This paper then focuses on one of the non-engineering programs, a three-year Diploma in Architecture (DARCH), maps itself to CDIO standards, specifically CDIO 3.0, where sustainability (CDIO optional standard 1.0) is one of the focuses.

LITERATURE REVIEW

As the world's climate continues to be impacted by the repercussions from global warming, teaching sustainability has become a priority education at all levels. We believe that a change in people's attitudes and behaviours is essential for sustainable development. To teach sustainability is therefore to adopt teaching methods that will change students' attitudes and behaviours towards sustainability. Some of the factors that affect student attitudes and behaviors towards the environment and sustainability include knowledge and level of awareness (Sahin & Erkal, 2017), as well as economic issues (Rosentrater & Burke, 2017). There are two approaches to stimulate increased levels of care for the environment and pro-environmental attitudes and behaviors (Pizmony-Levy & Michel, 2018). The two approaches are: one, through extra-curricular activities where students participate in sustainability events and initiatives that raise awareness of environmental issues and promote sustainability. The second approach, which is also the focus of this paper, is to integrate sustainability components into curriculum through a design-implement project. This can be done through the vehicle of an integrated design project where the students design a multi-storey residential development, stimulating professional practice by conceiving, designing, and implementing their project. This provides a practical and experiential experience in nature, related to real life conditions while gaining knowledge, involving students in critical thinking and reflection on action.

Technology, especially related software plays a key role in supporting the teaching of sustainability (Marouli, et al., 2016a). Example such as simulation software introduced to students for used in their project to analyse urban forms in relation to shadow, wind and solar insolation.

INTRODUCTION

Originally named as Diploma in Architectural Technology (DAT), the DARCH program began in Singapore Polytechnic as a drafting course in 1958, providing vocational training for students who will move on to fill the role of draftsman upon graduation. In the year 2003, the program adjusted its curriculum to expand its graduate profile from a draftsman to the role of an architectural assistant. With this adjustment, the program was then renamed as Diploma in Architecture (DARCH).

The key change in this adjustment is the introduction of design into the curriculum, allowing students the opportunity to apply the technical disciplinary knowledge acquired from the supporting courses/modules into a design project. This incorporation of design created a more varied, creative and competitive environment where students can thrive in being more innovative and solution-minded. Figure 1 shows a breakdown of the courses taken by students in their third year and how these individual courses contribute to a central design project known as the 'Integrated Project'.

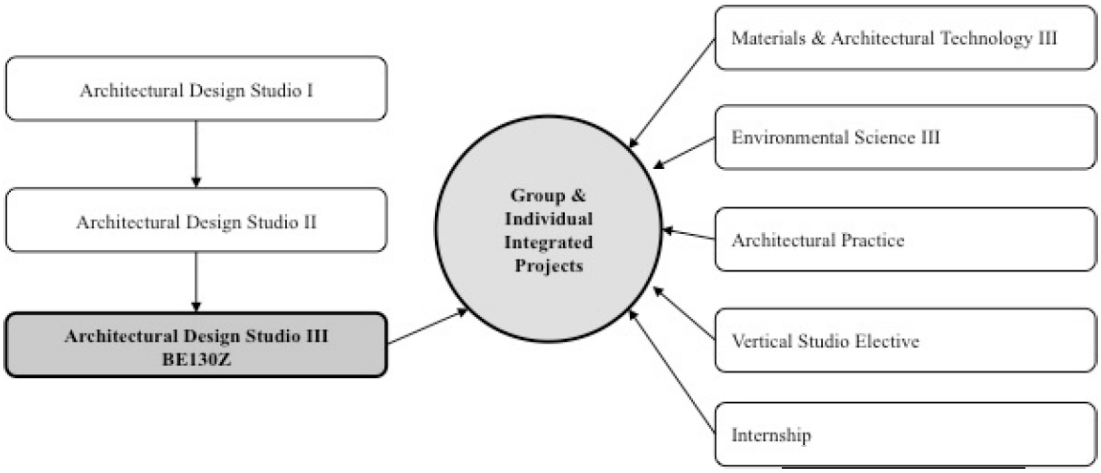


Figure 1 DARCH Integrated Project Pedagogical Framework

This new pedagogical framework mirrors the real-life phases of architectural production, allowing the students to easily assimilate to the actual process when they enter the workforce after graduation. In Singapore, these phases are articulated sequentially as 'Concept Design', 'Schematic Design', 'Design Development', 'Construction' and 'Completion'. As the names suggest, each phase is a development from the earlier phase, the project begins with abstract concepts, takes on schematic form, moving on then into details, before culminating in the actual construction of the building. The integrated project approach emulates this process through a series of curated learning activities that progress through the same stages and enabled by the vehicle of an individual design project.

What has just been described resembles the CDIO framework. Since the transition to DARCH, the faculties recognise that architectural students in training should be able to Conceive-Design-Implement-Operate complex value-added architectural schemes in modern team-based environments. They should be able to participate in the practice of architecture, contribute to the development of architectural design and work at professional standards. The architectural profession is not unlike the engineering profession in this aspect.

The likeness of the current structure in the DARCH pedagogy to CDIO makes the idea of articulating the curriculum as a CDIO curriculum potentially feasible and beneficial to the program as it allows the program to be evaluated and developed through an established system that is already in place.

THE CDIO MAPPING CHART

The adoption of a full CDIO framework for the entire DARCH program can be an arduous and lengthy exercise, especially for a non-engineering program with no prior experience. To simplify this initial transition, a decision was made to narrow the scope by focusing only on the aspect of sustainability. Besides easing the process, the focus on sustainability is also appropriate and strategic at this point in view of the current global trends as well as the introduction of the new CDIO 3.0 Syllabus. The following sections will describe how CDIO, as an education framework helps the program systematically breakdown the industry needs pertaining to sustainability and infuse the necessary skillsets into the curriculum.

To facilitate the mapping across to the CDIO framework, a chart to visualise and organise curriculum activities into the 'Conceive', 'Design', 'Implement' and 'Operate' stages of design was created. The intent for this chart is to allow the existing curriculum activities to be sorted into the respective columns presenting a basis for an initial assessment of the program with

regards to CDIO in the short term. Eventually, this 'live' chart will continue to aid the program lead and faculties in their design of the curriculum.

Running horizontally across the chart are the CDIO stages, starting with 'Conceive' on the left and ending with 'Operate' on the right, thereby forming the 'CDIO Stages' axis. Then running downwards, perpendicular to the CDIO axis, are the 12 standards of CDIO, arranged in its numerical order. This forms the 'CDIO Standards' axis. Together, these 2 axes allow curriculum activities or outcomes to be understood in relation to 2 particularly important aspects of the CDIO framework - the stage of the CDIO stages that they fall under and the CDIO standards they fulfil. As the entire chart is too large in scale, only a portion of it is reproduced in Appendix A.

USING CDIO STANDARDS TO DISSECT THE PROGRAM

This next section will describe the process of adoption where the CDIO standards were used to dissect the program requirements to gain a better understanding of where the curriculum stands with regards to the framework. This exercise also created focused investigations around particular aspects of the program, allowing gaps if any to be revealed. Since this mapping exercise focused only on mapping sustainable learning experiences into the program, the CDIO standards that were referenced were taken from the CDIO Optional Standards 3.0, Optional Standard 1 – Sustainable Development. Reference was also made to the *Rubric for self-assessment* (Crawley, 2022) to position the program based on its current offerings. And to ensure a more purposeful mapping exercise a target of level 3 on the rubric scale was set as the preliminary goal. This would therefore require the program to demonstrate that "explicit program goals and intended learning outcomes related to environmental, social, and economic sustainability and at least three substantial sustainable development learning experiences of increasing complexity including an introduction early in the program." (Crawley, 2022).

The dissection of the program using the lens of the CDIO standards was implemented according to the numerical order of the standards. However, this paper will only cover in detail Standard 1 and 2. The next few paragraphs will attempt to explain how the mapping helped the program emphasize environmental, social and economic sustainability as the context of the program. It will also explain how after the context is established; the context in turn frames the learning outcomes of the program.

While *Conceiving – Designing – Implementing – Operating* forms the primary context of the CDIO education model, there seems to be also a need to articulate secondary context(s) that would help clarify the needs of the industry. And in our case here, it is important to identify from the start a point of reference that can narrow down the relevant skillsets needed by the graduates to conceive, design, and implement sustainable architectural solutions acceptable by the industry.

The most common point of reference today appears to be the United Nations Sustainable Development Goals (UN SDGs). However, these set of goals are quite broad in definition, making the actual tie back to a specialised course such as architecture challenging. This led to a further industry scan, which surfaced another plausible point of reference that is more specific and relevant to the profession. This alternative point of reference that can form the secondary context is the Green Mark 2021.

Green Mark or Green Mark Certification Scheme is a rating system developed by the Building and Construction Authority (BCA) of Singapore since 2005 to evaluate a building's environmental impact and performance. In tandem with the Code for Environmental Sustainability of Buildings that came in force in 2008, these 2 building guidelines regulate and incentivise the development of sustainable building designs in Singapore.

Green Mark 2021 is the most current release of this rating system, and it consists of 6 different sections – (1) Energy Efficiency, (2) Intelligence, (3) Health & Well-Being, (4) Whole of Life Carbon, (5) Maintainability, and (6) Resilience, providing a comprehensive assessment of a building's impact to the environment. Each section comes with a detailed document listing down the various expected sustainable features or considerations required of a building design. It became obvious that if industry practitioners are obligated to meet these expectations, then students too ought to be trained with the needed skillsets. The pegging of the program to this building sustainability rating system as the secondary CDIO context will therefore ensure an alignment of the graduate profile to the industry needs.

Two interesting discoveries were also made in the attempt to draw Green Mark 2021 into the CDIO framework as its secondary context. Firstly, a closer study of the Green Mark Criteria showed that the expected considerations for sustainable features or design responses occurs at distinct phases of the architectural project life cycle, distributed across the stages of Conceive-Design-Implement-Operate. The Green Mark requirements could then be analysed and mapped accordingly into their respective stages, allowing the secondary context to be nested within the primary CDIO context. This would mean that students can hence also experience sustainable learning activities in accordance with the CDIO approach.

Secondly, the Green Mark 2021 Sections was found to be mapped to the UN SDGs by the authors of the rating system (BCA, 2021a). This added value to the choice of adopting Green Mark 2021 as the secondary context as it meant that the program would still be contributing to global sustainable goals indirectly through the rating system.

GREEN MARK AS THE BASIS OF CRAFTING LEARNING OUTCOMES

After narrowing down the point of reference that could serve as a context to emphasize environmental sustainability, we then moved on to allocate the specific detailed expectations of the rating system within the CDIO Mapping Chart. Not every criterion from the rating system was transferred to the mapping chart, only relevant ones that ought to be covered by the program was included. The selected criteria were then sorted to the most relevant CDIO stage. This was done by having the criterion descriptions written in white or black coloured tiles and distributing these tiles across the CDIO Stage axis. Each criterion would therefore find itself appropriated under the Conceive, Design, Implement or Operation column (see Appendix B).

This is a crucial step, as the visualisation of these Green Mark criteria across the CDIO spectrum allows us to read them as specific program goals that will in turn direct our efforts when we craft learning outcomes. When the learning outcomes are crafted with the intent to meet these goals, we believe that this will in turn help the program fulfil CDIO's Optional Standard 2 where "sustainability related knowledge, skills and attitudes, are explicitly addressed in program goals and learning outcomes" (Crawley, 2022). Furthermore, the placement of these goals within the CDIO Mapping Chart allows faculties to be better informed of how to organise their learning activities in line with project life cycles.

As mentioned earlier, the next step of the mapping exercise involves the crafting of learning outcomes in relation to Green Mark 2021 requirements. How this was done will be explained with the help of an example where the "Contextual Response" criteria found in the Resilience Section of Green Mark 2021 was translated into 3 separate learning outcomes parked under the 'Conceive' column and to be implemented within a 15-week Design Studio I (Architecture) course.

The 'Contextual Response' criteria requires the architectural proposal to:

> demonstrate how the site topography, microclimate, access and connectivity has informed the design of the urban form and site layout. A site analysis should be conducted to identify the relationships between human and physical geography of the site and inform how the building responds to these factors. Details should include the response to the urban grain, site connectivity and access, provisions and locations of amenities, and opportunities for green corridors. A series of simulations and studies of the project should also be undertaken that look at the microclimate and the response of the urban form generated, including, shading analysis, wind analysis and solar insolation studies. (Building Construction Authority (BCA), 2021b)

This work of analysing a project site occurs prior to the design of buildings, meaning during the 'Conceive' stage. Buildings designed empathetic to site conditions often takes advantage of the specific characteristic of the locale and results in less damage to the urban fabric. Climate responsive design are also known to cost less in terms of energy consumption. To produce the work needed to fulfil this criteria, 3 fundamental skillsets are embedded within the criteria, and we can dissect them as follows:

1) The ability to conduct site analysis to identify the relationship between human to physical geography;
2) The ability to design an urban form / site layout that is informed by the site topography, micro-climate, access and connectivity;
3) The ability to simulate and analyse the impact made by the building design on shading, wind and solar insolation.

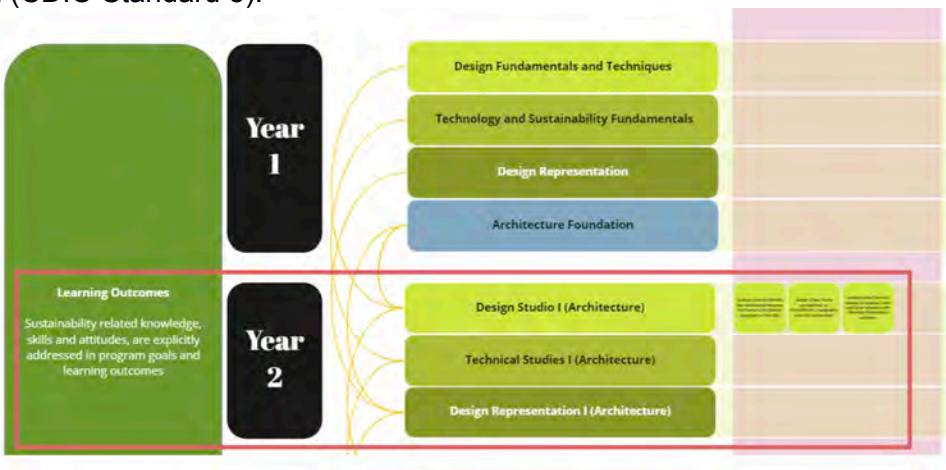
The above skillsets can easily be translated to the following corresponding learning outcomes:

1) Analyse a site to identify the relationship between the human and physical geography of the site;
2) Design urban forms sympathetic to microclimate, topography, and site connectivity;
3) Analyse urban forms in relation to shadow, wind and solar insolation using appropriate simulation software.

In the next section, we shall cover how the above-mentioned learning outcomes translate into learning activities within the Design Studio I (Architecture) course, a 15-week course taken in the second year of the 3-year program.

IMPLEMENTATION IN DESIGN STUDIO I (ARCHITECTURE) COURSE (DS1(A))

The desired learning outcomes are achieved through a horizontal integrated year two curriculum (CDIO Standard 3).



Year Two Integrated Curriculum with Core Courses

Through the vehicle of an integrated project where students design a multi-storey residential development, they simulate professional practice by conceiving, designing, and implementing their projects. This is achieved through incorporating a series of design-implement experiences (CDIO Standard 5) that provide students with the opportunities to apply and contextualise sustainability knowledge, skills, and attitudes with technological advances. Besides acquiring knowledge from DS1(A), students learn technical knowledge and software presentation skills through the support and integral of two other year two courses, namely Technical Study I (Architecture) (TS1(A)) and Design Representation I (Architecture) (DR1(A)) respectively.

As stated earlier, under Green Mark 2021 – GM:2021 Resilience (Re) Section, RE1.3 Contextual Response, the industry practitioners (design team) is to conduct Site Analysis / Simulation at the beginning stage of project design development. In DS1(A), an assignment on Site Study & Analysis is designed and implemented to allow students to go through the same process as practitioners do to simulate industry practices. Students are given a project site in Singapore to carry out the study and analysis in groupwork. This study also enables students to understand the project site and surroundings and prepares them for subsequent design development work of the integrated project. (Please refer to skillsets and learning outcomes mentioned above).

In year two course, emphasis is placed on the study of Singapore climatic influence on building design and user experience. As an integrated curriculum, besides gaining knowledge on climatic influences (sun path, shadow-casting, wind path etc) on building design in TS1(A), students carry out simulation study of these influences on building design using computer software. These design-implement experiences are gained whereby students explore and test out different alternatives / solutions of building orientations on the given project site after the site analysis has been carried out.

In the design of integrated project, design considerations on sustainability will be incorporated and be a key component under the assessment criteria. This integrated approach enables students to gain essential knowledge on sustainability from different disciplines (architectural, structural, environmental etc) and incorporate in the building design project in a holistic manner. Besides acquiring knowledge and skills, students develop awareness on sustainability and climatic impact on built environment. Through critical thinking and problem-solving processes in designing urban forms sympathetic to microclimate, topography, and site connectivity , students thrive being more innovative and solution-minded. Through the integrated curriculum and project, the course strives to change students' attitudes and behaviours towards sustainability.

REFLECTION ON IMPLEMENTATION AND FUTURE PLANS FOR DS1(A)

Based on a self-study approach (Marlon & et al., 2021), the course instructor of DS1(A) (co-author) reflected on students' learning experience whereby students apply and contextualize sustainability knowledge, skills, and attitudes with technological advances. These reflections were informed by students' feedback collected through survey questionaire on their learning and application of knowledge on sustainability. Quantative and qualitative students' feedback were analysed and informed by industry feedback and graduates' survey.

The instructor's reflections and future plan for DS1(A) can be summarised as follow:

1. Keep Courses Up To Date to Align with Development in Global, National and School Initiatives and Plans

Although sustainability has been incorporated in the Year Two program via DS1(A) and TS1(A), there is a need to further update the courses by identifying the essential and relevant knowledge on sustainability to teach in year two courses/modules for students' better learning

and understanding at their appropriate level. This is especially important with the recent revision of Green Mark – Green Mark 2021 (introduced in November 2021) and the adoption of a CDIO framework for the entire DARCH program focusing on the aspect of sustainability. This will apply to courses/ modules in the other two years (i.e. year one and three) where the vertical integration across the three years is a key element in the program.

With the global, national and school initiatives/ plans on sustainability being implemented or in the pipeline which constantly impacted the curriculum, it is a challenge for DARCH to identify areas which are appropriate and relevant to be included in the curriculum so as to stay up to date with all the developments. Once the breadth and depth of teaching and learning have been identified, it will be a smoother journey for both course/ teaching team and students.

2. Continue to Plan and Implement a Coherent Course Work for DS1(A) with Relevant Design-Implement Experiences with Real-Life Context and Focus on Sustainability

DS1(A), a 15-week course, was introduced to Year Two cohort in academic Year 2022/2023 Semester One as a revision to a preceding year course named Integrated Project Studio II. (Reasons for revision will not be elaborated here as they are not directly relevant to this Paper).

After Semester One, students went out to industry to do a 22-week internship Program in Semester Two. A survey was conducted after the 22-week internship on students' learning and application on knowledge of sustainability. 84 Students from 5 classes were invited to participate in the survey. 58 responses were collated, and results were tabulated in Table 1 below.

Table 1. Student Feedback Survey *(Showing Percentage of Quantitative Responses)*

AY22-23 (58 responses)			
	Questionaire	Yes	No
Q1	During Year 2 of study, I have acquired knowledge on "Sustainability" (e.g. site analysis, climatic response in design, research on sustainable features in precedent study etc) in the module Design Studion I (Architecture) which is useful for my learning	93%	7%
Q2	During internship, I was able to apply the knowledge on "Sustainability" learnt in school to my work	43%	57%
Q3	During internship, I was involved in:		
	Greenmark : To participate in the design processes involved in enhancing the sustainability status of the building (e.g. through the application of the Greenmark, Buildability Score, the usage of relevant software etc)	10%	
	Green Initiatives : To participate in the research, proposing, implementation and documentation of current and future sustainable features in the built environment	19%	
	Others	5%	
	None of the above	72%	
Q4	If your answer for Question 3 is "Others", please write briefly below the area/ areas you were involved.	qualitative feedback summary in discussion section	

Based on the student feedback, observations were made and possible conclusions were drawn and suggested. Please see below for elaboration.

On Students' Learning on Sustainability

93% (about 54 students of 58 responses) gave positive feedback on their learning of sustainability (Q1 of Table 1), informing that they have learnt and acquired knowledge on sustainability. The feedback indicated that students are able to comprehend the course materials on/ related to sustainability and apply the knowledge to the course work through the integrated project/ assignments. It also suggested that students have Integral and meaningful learning experiences through the coordinated integrated project assignment.

In future planning and implementation of DS1(A), aside to imparting knowledge on sustainability through the design-implement experiences in lessons, activities raising awareness on sustainability and encouraging green practices are to be incorporated in the curriculum. The integrated project / assignments will continue to hone students' critical thinking and problem-solving skills. The module aims to reinforce teaching and learning of analytical skills which is currently lacking in students as observed from the site analysis assignment. To enable students to understand the complexity of real-world project, course team will plan for a coherent course work to include all essentials (but not overloaded) with relevant real-life learning experiences for students.

On Students' Application of Knowledge of Sustainability at Work during Internship

As the course aims to allow students to have real life industry experience, the integrated project / assignments are designed to simulate real life industry practice and incorporate requirements practiced in the industry, The survey conducted after students' completion of their 22-week Internship Program aims to find out the relevance of the teaching and learning of sustainability.

Question 2 of the survey (Q2 of Table 1) asked if knowledge on sustainability learnt in school has been applied in students' work during the internship. 43% (about 25 students of 58 responses) gave positive feedback which is encouraging. The result suggested that 1) students are able to identify areas of sustainability in their work and this helps to relate to their learning in school and 2) industry has involved our students in works related to sustainability which will reinforce their learning. The intended and planned design-implement experiences incorporated in DS1(A) have been reinforced during internship.

Question 3 and 4 of the survey (Q3 and Q4 of Table 1) asked for areas of involvement in sustainability to find out more details and specific areas of students' involvement. This is to check the relevance of the course's teaching and learning on sustainability to keep abreast of industry practice and development of sustainable practices in the industry.

As for the next cohort, a feedback survey with more specific questions related to key areas of sustainability will be conducted at end of Semester One before the commencement of internship to prepare students for internship. A second survey will be conducted after the internship program. This will help to close the loop of circle to have useful observation and conclusion.

Validation of DARCH Program by Graduates and Industry

Graduate Feedback

Based on recent Graduate Satisfaction Survey (2021), the program scored well in being up to date according to the requirements of the job market at the point of graduation. On a scale of 4, it achieved a score of 3.14, slightly higher than the polytechnic's average of 3.09.

Industry Feedback

As the DARCH program aims to produce graduates who are work ready for the industry, the program team constantly gets feedback from the industry of our interns and graduates to keep pace with the development of the industry and to make our course relevant. The curriculum is therefore designed and implemented to simulate real life practice. Students are taught relevant and up-to-date software skills. For example, even prior to the introduction of Green Mark 2021, GM:2021 Resilience Section on Contextual Response, DARCH has already prepared the students to do site analysis. Students are able to pick up simulation software to carry out simulation on environmental influence required for site analysis.

CONCLUSION

The embarkment of incorporating CDIO education framework for non-engineering courses, in this instance, DARCH, in the School of Architecture and Built Environment (ABE) is timely. As demonstrated above, the practice of many of the CDIO standards are in place, less only spelt out explicitly. The mapping exercise has also aided the program to re-inspect its alignment with industry needs, especially in sustainability. A tighter engagement with building codes requirement can now be established ensuring a highly relevant graduate profile, capable of meeting the needs of the industry. Moving forward, using the CDIO Standards to improve on the current DARCH curriculum will help ABE path the way to make CDIO's 12 standards, the guiding principles and framework for both its engineering and non-engineering courses for continuous improvement.

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BIOGRAPHICAL INFORMATION

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Yiat Yam Leong is a senior lecturer and an academic mentor of Teaching and Learning Unit in the School of Architecture and the Built Environment at the Singapore Polytechnic. Passionate in teaching and keen in learning, she explores different pedagogies to improve students' learning and to help teaching staff in teaching and learning.

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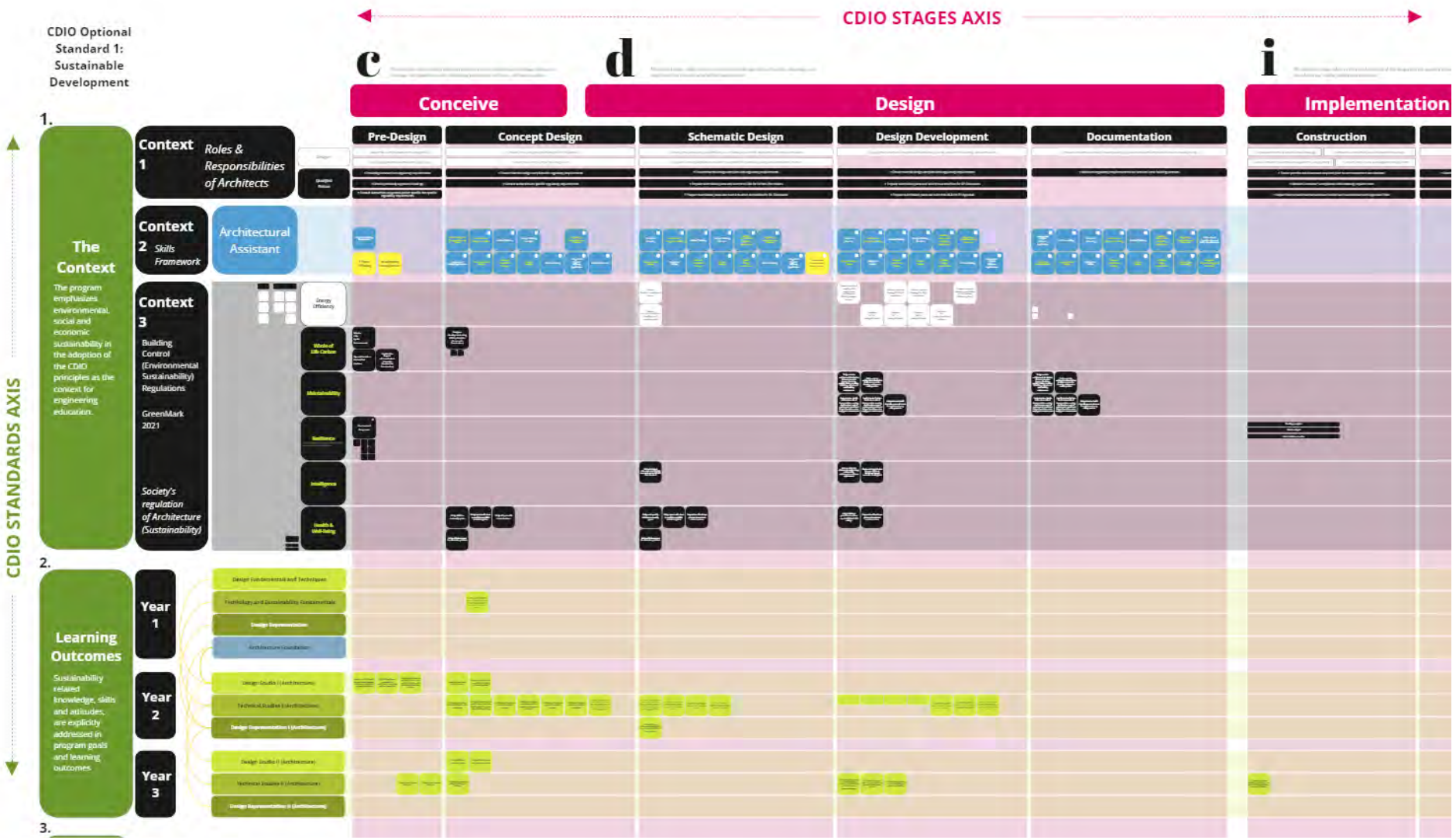
APPENDIX A – CDIO Mapping Chart (Partial)



APPENDIX B – Green Mark Criteria Descriptors in CDIO Mapping Chart