U OF T CIVIL ENGINEERING
ACADEMIC PLANNING COMMITTEE

FOURTH-YEAR DESIGN PROJECT COURSE

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1 PURPOSE OF THIS DOCUMENT

This document describes a proposed new fourth-year design project course. It includes a statement of the pedagogical objectives of the course, a summary of the primary features of its content and delivery, as well as an estimate of the resources that will be required to implement the course.

This document is currently a working draft for discussion within the Academic Planning Committee. It will be refined and modified as required by this Committee. Following this process, it will be presented in its final form to Department Council for approval.

2 BACKGROUND

The development of a new fourth-year design project course for Civil Engineering has been undertaken in response to a mandate given to all departments by the Faculty. The Decanal Task Force on Curriculum Change recommended to Faculty Council that departments create and implement such a course, and proposed a broad specification for its content and delivery. These recommendations, which were adopted by Faculty Council, define the minimum requirements for the fourth-year design project course from the Faculty's perspective.

The recommendations of the Task Force on Curriculum Change are attached to this document as an appendix. The most relevant aspects of these recommendations are summarized as follows:

1. The course shall carry a weight equivalent to two single-term courses
2. The course shall contain the following elements: (a) an integrative element, (b) a design element, and (c) an independent work element

3 APPROACH TO THE DEVELOPMENT OF THE COURSE

We regard the requirements of the Decanal Task force as a minimum specification for the fourth-year design project course. As such, these requirements constitute not only an obligation to fulfill, but also an opportunity to create and deliver the best such course anywhere in Canada. By offering a design course that is truly excellent, we will greatly enhance the ability of our graduates to become leaders in their profession and to be significant agents for positive change in society. Recognition of the high quality of our design course will increase both the effectiveness of our undergraduate recruitment efforts and the value of our graduates in the job market.

Our development effort has thus proceeded from the basis of first principles, according to the following steps:

1. Identify the essential features that define the design process as it relates to civil engineering

2. Define the primary elements of an effective approach to teaching and learning the features identified in the previous point
3. Review our current curriculum to establish its strengths and weaknesses in relation to the primary pedagogical elements defined in the previous point
4. On this basis, define the primary objectives of the course
5. Develop course content and means of delivery to achieve these objectives
6. Review the course as developed to demonstrate that it is in accordance with the Faculty's requirements
7. Estimate resources required for delivery

4 THE NATURE OF DESIGN IN CIVIL ENGINEERING PRACTICE

If we wish to teach design, then we must first establish consensus on what it is we actually need to teach. This issue is not trivial, because design means different things to different people. Within the current curriculum, for example, the term "design" is used to refer to the creation of new ideas for civil engineering works, the dimensioning of components within systems that have already been defined, and a collection of professional skills such as project management, teamwork, and cost estimating.

In its broadest sense, design is defined as the act of conceiving and mapping out ideas for useful things. Engineers generally use a more elaborate yet equivalent definition, in which the design process is broken down into four component activities:

1. *Definition* of what the artifact (the "useful thing" to be designed) is required to do, often referred to as "design criteria"
2. *Creation* of a new idea for the artifact, often called a "design concept"
3. *Validation* of the design concept, i.e., demonstration that it can satisfy the design criteria
4. *Refinement* of the design concept, i.e., producing a description of the design that is biddable and buildable

Each activity is important, yet each employs distinct thought processes.

Definition of design criteria is primarily an exercise in gathering and organizing facts. This activity can be relatively straightforward. For a bridge design project, for example, defining design criteria could be a simple as specifying an applicable design standard. In general, however, design criteria can be complex, in response to demands from owners and users for projects that address important environmental, social, and aesthetic concerns. In many cases, criteria related to these issues cannot realistically be expressed in quantitative terms.

Creation of design concepts is, as its name implies, a creative activity. As such, it has much in common with artistic activities such as composing a symphony, writing poetry, or painting a landscape. In all of these activities, new ideas are generated through the combination, synthesis, and transformation of existing ideas. What distinguishes engineering design from creative activities in other fields is that scientific principles figure prominently in the body of existing ideas that is brought to bear in the creative process. Whatever the field, the creative process is a highly individual activity.

All other things being equal, the quality of a given design concept depends on both the quality of the conceptual raw material that is used in the creative process (the body of existing ideas that is readily available to designers) as well as the quality of thinking that is used by designers in the generation of new ideas from this raw material.

At some point in the design process, designers must convince themselves and their clients that the design satisfies the design criteria. In most cases, it is also necessary to show that the proposed concept is in some sense better than other potential solutions. Given the cost, size, and complexity of civil engineering projects, it is not feasible to demonstrate this using the finished product after construction, or even using a fully refined design. Rather, the "goodness" of a given concept must be established while the concept is still in a relatively preliminary state. This is the primary purpose of Activity 3.

Validating a rough concept is a complex and challenging task, not only because the definition of the design is incomplete, but also because important criteria often cannot be adequately dealt with in quantitative terms, or are in conflict with each other. In such cases, particularly when social or aesthetic impacts are involved, engineers tend to defer to owners or users. The history of civil engineering clearly shows, however, that such an approach often produces mediocre results, and that better solutions are often produced by engineers who have developed a strong sense of what makes a design "good".

Contractors require a description of a given design that is sufficiently detailed to allow them to bid it and build it. The effort required to transform a valid design concept into a final design is considerable. It is, however, a relatively straightforward activity. Refinement of concepts generally involves analysis and dimensioning of components, neither of which demands particular creativity.

Refinement is important. Putting insufficient reinforcement into a concrete beam, for example, can lead to its collapse. Fundamentally, though, it is less important than Activities 1 through 3. If a valid design concept does not exist, refinement alone cannot generate it. If a concept exists but is fundamentally flawed, no amount of refinement can rescue it.

5 THE BASIC ELEMENTS OF DESIGN ENGINEERING PEDAGOGY

Given the insights presented in the previous section, we can begin to define an effective approach to teaching design engineering.

We begin with the observation that Activity 4, the refinement of design concepts into a final design, is already reasonably well covered in the current curriculum. Most of what we teach deals with the analysis of engineering systems and the dimensioning of components belonging to these systems, which are the two primary elements of the refinement effort. Feedback from engineering practice confirms that what our graduates lack is not so much the ability to analyze and dimension systems that have already been defined, but rather the ability to define such systems from scratch. In defining how best to teach design, therefore, we will restrict our attention to Activities 1, 2, and 3, i.e., the definition of design criteria, creation of design concepts, and their validation.

5.1 Activity 1: Definition of Design Criteria

As stated in the previous section, the definition of design criteria is primarily an exercise in collecting and organizing facts. In practice, much of this effort is driven by the client and other stakeholders, i.e., by forces outside the control of the designer. It is the designer's responsibility to be aware of requirements and constraints that can affect the design, but generally it is the client who has the final say in their definition.

From a pedagogical perspective, therefore, the primary issue is to challenge our students with projects that involve complex and difficult design criteria. The actual specification of these criteria, however, will largely be done by teaching staff acting in the role of the client or other primary stakeholder in a design project situation.

5.2 Activities 2 and 3: Creation and Validation of Design Concepts

Preparing students to become proficient at creating and validating design concepts involves three primary pedagogical elements: *knowledge*, *skill*, and *values*.

In the previous section, we defined the creative process as the generation of new ideas by synthesizing existing ideas. As well, we defined the validation activity as demonstration of the "goodness" of a given design concept. From this perspective, the quality of a given design depends on the following factors:

1. The richness of the body of existing ideas that can be combined and transformed into new ideas. The body of existing ideas that is brought to bear in the design process, i.e., the conceptual building blocks and tools used to create new ideas, will be referred to as *knowledge*.
2. The quality of the thinking used in synthesizing new ideas from existing ones. The ability to produce good design concepts from a given body of knowledge will be referred to as *skill*.
3. The quality of the designer's judgement in determining which of many design concepts "best" satisfies complex design criteria. This sense of what constitutes a "good" design will be referred to as *values*.

The pedagogical implications of each of these elements will be discussed in the following subsections.

5.3 Knowledge

Although most of the current curriculum deals with conveying knowledge to students, one important aspect of knowledge is noticeably absent, namely, knowledge of complete works of civil engineering. Our pedagogical approach is to build up knowledge from first principles of science, moving towards completed works. Due to constraints in the curriculum as well as the perspectives of a large proportion of our teaching staff, however, we rarely arrive at the final product in our courses. In structural engineering, for example, students learn how to calculate the reinforcement required to carry a given bending moment in a given beam, but they are taught little about how to lay out beams in a floor of given geometry. The lack of such knowledge hampers our graduates as they attempt to develop design concepts of their own.

In addition to building knowledge from the bottom up, therefore, we need to work from the top down. Students need to be exposed to finished works of engineering, and challenged to understand the reasons behind the most important decisions that define the system. From a design perspective, the significance of this approach is not for students to copy existing solutions, but rather to extract insight from them that can be used as starting points for their own designs.

5.4 Skill

Becoming proficient at creative thinking is difficult. Each individual thinks differently, and this must be recognized in our pedagogical approach. We cannot realistically expect to be effective in conveying creative skill by imposing a uniform mode of thinking on all our students.

This does not imply, however, that design skill cannot be cultivated in a university environment. Starting from the perspective that students must acquire design skill by doing design, we can help them in this process in the following ways:

1. Providing them with an environment in which mistakes are viewed as learning opportunities, not as signs of intellectual weakness
2. Presenting them with general strategies for organizing and using available knowledge in the design process
3. Exposing them to the decision-making process used by actual practicing designers. Many designers have written about how they overcame challenges on their projects; this material can be made available to students.
4. Starting with small design challenges that can be easily overcome and progressively increasing the level of difficulty. In this regard, the notion of teaching design through re-design of existing works can be particularly effective.

Above all, we need to convey to students that skill in design is not a talent given only to a favoured few, but rather is something that all students can acquire with proper guidance. Not all of our graduates will go on to become brilliant designers, but it is reasonable to expect that all of them can become competent designers.

5.5 Values

In the current curriculum, we tend to emphasize economy of materials and low construction cost as the primary measures of quality of engineering works. Although there is growing awareness of the importance of environmental issues, we have not yet found an effective way of incorporating these issues into many aspects of the “traditional” curriculum. Issues such as aesthetics and community concerns are left largely untouched. The fact that these issues cannot credibly be dealt with by quantitative means is a likely reason for their absence, but this does not mean that they are not important.

The objective is to challenge students to think critically about these issues and to develop their own sense of what makes a design “good” when it must satisfy complex and conflicting criteria. We can help them in this process by taking a critical perspective ourselves, i.e., by making them aware that we have values of our own and that we are willing to use them.

A primary opportunity for us to demonstrate the importance of values to students is in our studies of completed works of engineering. We can and should calculate the behaviour of these works in terms of physical quantities such as force and stress, but we then need to use this information as a basis for statements on how well the system satisfied complex criteria relating to environmental, social, and aesthetic issues. The point is not for students to accept our values without thinking, but rather for us to encourage them to develop values of their own.

6 OBJECTIVES OF THE PROPOSED COURSE

The primary objective of the fourth-year design project course is for students to acquire proficiency in creating and validating design concepts for civil engineering works that involve complex design criteria. The course will:

1. Provide students with the foundation of a body of knowledge that can be used as a starting point for design of works within specific areas of civil engineering
2. Give students an opportunity to develop skill in creative thinking
3. Provide opportunities for students to acquire and apply a personal sense of values to the validation of design concepts

We have clearly established the focus of this course on the creative aspects of the design process. Specifically, we have not included the refinement of design concepts as one of the primary objectives of the course. As stated previously, the portion of the curriculum currently devoted to refinement of design concepts is believed to be sufficient, especially since relatively little teaching time is currently spent on the creative aspects of design.

This course is not intended to produce, on its own, fully proficient designers. Design is a practical activity and, as such, learning to design requires an apprenticeship of several years in engineering practice. For this apprenticeship to be effective, however, students must enter practice with a basic set of knowledge, skill, and values that will serve as a framework in which they can continue their professional education during their early years of practice.

7 PRIMARY FEATURES OF THE COURSE

As its name implies, the proposed fourth-year design project course will require students to undertake the design of a work of civil engineering. The primary features of the course have been developed to accomplish the objectives stated in the previous section. These features, and the reasons for their choice, are described below:

7.1 Mandatory Course

The course will be a required course for all Civil Engineering students.

7.2 Two Components

The course will consist of the following two primary components:

1. *Design project.* Students will complete a design project of a work of civil engineering in accordance with requirements defined in Section 7 of this document.
2. *Case study.* Students will also perform a critical study of a completed work of civil engineering with project requirements similar to those of the design project described in under the previous point. Students will complete the case study before they begin work on the design project.

   Students require a body of knowledge of completed works to maximize the learning opportunities offered by a design project. Without such knowledge, students will find it difficult and frustrating to get started with their own design concepts. The case study has been included as an integral part of this course because the current curriculum does not provide students with sufficient knowledge in this area.

Providing a case study helps to make the design project a meaningful learning experience for students within a broad range of ability. Students who wish to deviate significantly from the case study in developing design concepts of their own are free to do so, as are those who wish to stay closer to the case study and treat their design project as an exercise in re-design.

By providing an in-depth case study rather than lectures, students are offered an important opportunity for independent learning. Through the case study, they will acquire knowledge with a clear purpose, which is typically the way engineers learn on the job. This way of learning will also help the department to keep the teaching resources required for this part of the course at a reasonable level.

7.3 Two Terms

The course will extend over terms 4F and 4W. The case study will occupy all of term 4F; the design project will occupy all of term 4W.

The two options for timing of the course are to put both units of the course in one term or to provide one unit in each of the two fourth-year terms. Given the need for a separate case study before the design project gets underway, it makes sense to spread the course over two terms. Having two separate deliverables, one in December and the other in April, helps to balance the level of student activity through the year.

7.4 Design Studios

The fourth-year class will be divided into studios of five to ten students. Each studio will be supervised by one instructor. Members of a given studio will complete the same case study and will complete a design project based on the same set of design criteria. Each studio will meet with its instructor on a regular basis (generally once a week) to review the progress of the work.

Face to face interaction between students and instructor has immense pedagogical value. It is a primary component of the process by which students learn design skills by doing actual design work. Fair and insightful criticism, presented in a positive atmosphere, will allow students to regard mistakes as learning opportunities rather than signs of intellectual weakness, as well as giving students pride in their successes.

The studios also allow students to benefit from regular interactions with their classmates. Through this contact, they will come to appreciate that a single problem in civil engineering can have many different solutions. In addition, they will develop an awareness of the struggles faced by their peers and learn that they are not alone in this regard.

7.5 Individual Work

Each student will be responsible for completing the case study and the design project on their own.

Although there is pedagogical value to group design projects, the value of individual work was determined to be greater in this case. Individual work ensures that each student has maximum opportunity to benefit from all of the learning opportunities offered by the course. Individual work also allows each student to take real ownership of their project and pride in what they were able to achieve on their own. We believe that this will be a significant factor in increasing the confidence of our students in their abilities as designers.

7.6 Level of Detail

The design project shall be completed to a level of detail that allows its feasibility to be demonstrated. Detailed design calculations, buildable plans, and detailed cost estimates are not required.

Although there is nothing wrong per se in including the refinement activity in the design project, there is not enough time available to do this without decreasing the time devoted to creation and validation of design concepts, which is the primary objective of the course. As stated previously, the primary pedagogical need is not for further practice in refinement of design concepts, but rather in their generation.

7.7 Thematic Content of Projects

To ensure that the course reflects the current realities of civil engineering practice and also prepares students for challenges of the future, the following requirements are proposed:

1. Projects should involve the solution of problems that are real and significant. Problems that involve aspects of life in urban society are encouraged.
2. The problems addressed by the projects should challenge students to develop designs that are ambitious and grand. Projects that involve the application of new technologies are encouraged.
3. Projects should involve a major technical area and at least one minor technical area, as well as significant social, environmental, or aesthetic issues.
4. Projects should have a strong focus on serving the needs of people in society. The development of new tools for analysis of systems, for example, would not be considered a valid topic for a design project, since the primary users of these tools are research or design professionals.
5. The design project is not a research project. Research deals with the creation of new knowledge; design uses knowledge to generate new ideas for useful things.

   Similarly, the design project is not an investigation of a problem. Its outcome must be an engineered solution, not merely a description of what is wrong.

Regarding Points (4) and (5), it is emphasized that the intent of the design project course is not to have students work on projects based on the current research interests of faculty members in the department. It is likely that some of the research areas of department colleagues will not produce topics for design projects that satisfy the objectives outlined in this document.

8 FOURTH-YEAR THESIS

In a recent meeting, Faculty Council approved a motion to remove the fourth-year thesis as a mandatory requirement for the B.A.SC. degree from the Faculty's perspective. How the thesis fits into the curriculum, therefore, is now a matter that is left to the discretion of each individual department. We propose to maintain the thesis as it is currently implemented, except to change it from a mandatory course to an elective course.

Requiring students to do both a two-weight design course and a single-weight thesis was considered to be an excessive workload that was not commensurate with the expected pedagogical benefits. Many of the objectives that were accomplished by the thesis (e.g. independent work, written and oral communication) will be accomplished by the design course. Those students who wish to gain experience in research through independent work will still be able to do so by opting to add the thesis to their program.

9 RESOURCE REQUIREMENTS

9.1 Faculty

Faculty resource requirements have been estimated based on the following assumptions:

1. There will be approximately one hundred students in the fourth-year Civil Engineering class
2. The average size of each design studio will be eight students
3. The teaching load of a two-term design studio is equivalent to that of a conventional one-term lecture course

The number of students per studio proposed in Assumption (2) is considered to be the maximum average size of studio that will permit us to deliver a course that satisfies the objectives defined previously.

Assumption (3) is based on consideration of the expected duties of a studio leader, which will include regular formal meetings with students, informal consultations, marking of work, preparation of studio and case study background documents, and possibly site visits.

Based on these considerations, we will need teaching staff for the equivalent of approximately 12 one-term lecture courses.

We have not counted as teaching load the participation of teaching staff in support of the "minor" technical area as defined in Section 7.7. The duties associated with supporting a minor technical area will include discussions with the studio leader during the summer planning stages to identify areas of pedagogical interest within the case study and design project, and possibly to provide background documents to assist in preparing the studio. During the school year, participation would be limited to attendance at two or three meetings of the design studio. No other interaction with the students has been considered. This effort has been estimated to be similar to the effort currently required for the supervision of fourth-year theses. Since this effort is not currently counted as teaching load, we propose not counting the effort required to support a minor technical area of the design course.

The primary demand for teaching staff, therefore, will be for studio leaders. With regard to meeting this demand, we make the following recommendations:

1. Studio leaders should be taken from our own permanent teaching staff. Although many practicing professionals have a suitable background for leading a studio, we do not believe that they have the time to be available on campus for informal consultations with students on a regular and frequent basis.
2. Our current teaching responsibilities take up all available permanent teaching staff. We therefore propose that, in the short term, the demand for the fourth-year design course be met on an overload basis. Colleagues who lead a studio would have a teaching load of four course equivalents and would be paid the standard stipend for one course equivalent. This stipend would be based on a studio size of eight students, plus or minus a small tolerance. Studios that exceeded the maximum limit

would not be permitted. Although studios that had fewer students than the minimum limit could be considered, the overload stipend would be adjusted accordingly.

3. We believe that there are ways to rationalize other areas of the curriculum that will reduce demand. This gain in capacity can then be used to help staff the fourth-year design course.

9.2 Teaching Assistants

We propose to assign a one-term-equivalent teaching assistant (approximately 60 hours) to each design studio. Teaching assistants would work primarily in the summer, to assist studio leaders in assembling background materials, organizing site visits, and other tasks required to prepare for the studios.

At this time, we do not recommend involving teaching assistants with the studios during term. Our current graduate students have little or no proficiency in the creative aspects of design; there is therefore little to be gained in involving them with the undergraduate students.

9.3 Space

Seminar rooms are required for the weekly meetings of the studios. One of the primary activities of these meetings will be for students to present their designs (in various stages of completion) to the members of the studio, and to receive critiques of their work. We therefore require, above all, lots of blank wall space for hanging up drawings, facilities for electronic projection, and flexible seating. The room should have natural light and good ventilation.

Assuming twelve studios meeting two hours per week, the demand on space will be 24 hours per week. This warrants having a seminar room designated specifically for the fourth-year design project.

We should also make provision for a more public forum in which designs can be presented and critiqued. Final presentations of design projects at the end of term would be one such occasion in which a wider audience would be welcome. There is no need to restrict ourselves to booking rooms for such events. In the Department of Architecture at the ETH in Zurich, for example, final critiques are held in public spaces such as lobbies of buildings and other large open areas. Temporary partitions are installed for hanging drawings and folding chairs are provided. This is not the only way of inviting a wider participation in the design course, but it does work well in Zurich.

The details of a larger forum for presentation and critique have yet to be worked out. At this stage, however, we can state that this issue need not have a controlling impact on scheduling or planning of the design course.

It would be certainly be beneficial to have dedicated space for students to work on their designs throughout the week (a physical “design studio”). The present lack of such space, however, does not significantly impair our ability to deliver an excellent design course to our students. Because the design projects are proposed as individual efforts, there is no need to provide space for collaboration. Because we emphasize conceptual design (creation and validation), there is no need for dedicated computer or testing facilities.

10 Initial Implementation

The Faculty Curriculum Committee has directed departments to begin implementing this course in the 05-06 academic year. We will proceed with a pilot implementation of this course in 05-06, involving approximately 25 percent of the 0T6 class. The remaining 75 percent of the class will follow the current program, with a required fourth-year thesis. Phasing in the course with a subset of the class will allow us to fine-tune its delivery before it goes to 100 percent implementation in 06-07.

In preparation for delivery in September 2005, we will need to identify a course coordinator and studio leaders. This will be done as part of the normal planning process for teaching assignments for the 05-06 year, which is expected to take place in April of 2005.

We propose to hold a workshop in the summer of 2005 for members of the teaching staff who are interested in being studio leaders in the 05-06 academic year. This workshop will help prepare colleagues for this effort and will ensure a suitable level of coordination and common standards among the individual studio initiatives.