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"TAKING INVENTORY" Feeding the Loop: The Role of Professional Education in Successful Building Science Technology Transfer

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What is feeding this loop? If the conference theme wishes to examine the circular flow of cutting edge information and practice throughout the industry, we must also recognize the importance of education as it informs the new graduates that continually flow into the field. Is education at the cutting edge of building science technology? Do students have the opportunity to take specific courses in building science? Are they core? Are they elective?

Are there reasonable standards and expectations in current curricula across Canada with respect to the teaching of building science? If there is deemed to exist a break in the loop, as defined by the conference theme, in putting principles into practice, then the role of education must be examined to see its potential for reducing the gap. If we are continually feeding graduate architects and engineers into the building profession, then their relative degree of technical preparation will ultimately impact building envelope design. As not every project team can include a certified "Building Scientist", the level of expertise of the "general architectural and engineering practitioner" has the potential to either raise or lower the quality of building science that is normally included in the envelope design of everyday buildings.

The scope of this research sought to examine the curricular content in Accredited Programs of Architecture and Engineering across Canada for evidence of the teaching of courses in Building Science and Building Envelope Design, as well as the opportunity for a Building Science specialization. The examination was restricted to University level programs in Architecture[i], and the 21 CEAB Accredited programs in Civil or Building Engineering.[ii]

THE INVENTORY:

In general terms, the data collection took place "on line", searching through the University web sites for course calendars and content descriptions for each of the 11 Architectural and 21 Engineering programs generally for the keywords "building science" and "building construction". Course lists and descriptions were also examined for specific content in any building technology courses. In some instances email contact was made to obtain enhanced course descriptions or clarifications where the online information was either incomplete or inconclusive.

Comparing the course descriptions for courses in building science, versus general building technology, established that courses labeled "building science" dealt with envelope performance issues in a greater level of detail, where "building technology" courses might have some lectures on the building envelope and refer to some of the more technical aspects that affect performance,

but that this would be a subset of much broader issues that would typically also include structural systems.

Additionally, the governance rules that determine accreditation of both Architecture and Engineering programs were examined. Such criteria can be seen to potentially influence course content and direction.

An Inventory of Architectural Programs for Building Science Teaching:

For the purposes of the chart below, courses have been separated into those that were specifically noted as "building science" directed, versus those with a more general emphasis on the "construction" of the envelope as an element of the entire building. An examination of the course descriptions would indicate that less technical analysis of performance is contained in the latter courses. Building construction courses look at general principles of heat flow. An examination of the course outlines and descriptions indicated that detailed analysis of moisture flow was typically not investigated. Course descriptions for Building Science placed an emphasis on the envelope (over the structure) and included assessments of performance regarding heat flow, moisture flow, water penetration, durability and solar characteristics.

Courses were also separated into their core/required versus elective status. An elective status makes the number of graduating students who have taken the course unpredictable.

School	**Program**	**Building Construction**		**Building Science/Envelope**	
		Core	***Elective***	***Core***	***Elective***
University of British Columbia	3 year M.Arch.	2 courses			1 course
University of Calgary	3 year M.Arch.			2 courses	
University of Manitoba	3 year M.Arch.	3 courses			
University of Waterloo	4+2 M.Arch.	3 courses		1 course	1 course
University of Toronto	3 year M.Arch.			2 courses	
Carleton University	4+2 M.Arch.	3 courses			
Ryerson University	4 year Bachelor	1 course		3 courses	
McGill University	3+ 1 ½ M.Arch.	2 courses	1 course		
Universite de Laval	M.Arch.	2 courses		1 course	
Universite de Montreal	3+2 M.Arch.	4 courses			
Dalhousie University	2+2 M.Arch.	3 courses		2 courses	

As can be seen, all University level Architecture programs in Canada have significant course offerings that speak to issues of the building enclosure and its performance. Programs at Manitoba, Carleton, McGill and U Montreal do not have specific courses that address building science or a detailed presentation of building envelope issues. Toronto and Calgary both teach building construction with a building science emphasis. Ryerson offers a specific program stream in architecture directed towards the examination of building science. The balance of schools have curricula that speak to general issues of building construction, as well as more specific, detailed instruction in the area of building science".

An Inventory of Engineering Programs for Building Science Teaching:

A similar analysis was done for the accredited engineering schools in Canada. Although the data collection searched for calendar entries in the field of "building science" in all engineering disciplines, including Mechanical Engineering where many more scientific preparatory courses are offered, calendar and course descriptions in departments of Civil, Environmental and Building Engineering were examined in greater depth for courses dealing very specifically with the building envelope.

School	**Program**	**Building Construction**		**Building Science/Envelope**		
		Core	***Elective***	***Core***	***Elective***	***Instructor***
University of Alberta	Civil					
University of British Columbia	Civil				1 course (undergrad)	
Carleton University	Civil					
Concordia University	Building, Civil and Environmental Engineering	1 course (undergrad)		3 courses (undergrad)	2 courses (grad)	*Fazio, Haghighat*
Dalhousie University	Civil					
Ecole de Technologie Superieure (University of Quebec	Baccalaureat Genie de la Construction	1 course				
Lakehead University	Civil					
University of Manitoba	Civil					
McGill University	Civil					
McMaster University	Civil				1 course (grad)	*Drysdale*
Memorial	Civil					

University of Newfoundland						
University of New Brunswick	Civil					
University of Ottawa	Civil					
Queen's University	Civil					
Royal Military College of Canada	Civil					
Ryerson University	Civil					
University of Saskatchewan	Civil					
University of Toronto	Civil				3 courses (grad)	*Presnell*
University of Waterloo	Civil				3 courses (grad)	*Straube*
Western University	Civil					
University of Windsor	Civil					

The lack of courses in both general building envelope design as well as building science more specifically, is easily evidenced by the voids on the chart. Ninety percent of engineering programs in Canada provide no opportunity to engage in issues of building science, and building envelope design and testing, through either mandatory or elective courses. The few building science courses that are offered seem to be normally given at the graduate level, from which one *might* infer significantly reduced enrollment. During a recent interview with Dr. John Straube at the University of Waterloo, who teaches both in Civil Engineering and Architecture, he indicated that he is seeing increasing enrollment in his graduate level Engineering course offering of Building Science and Technology. Enrollment in this course is presently 57 students. He cites an increased student awareness of the deteriorating state of the environment as the reason students are citing for taking the course. Such enrollment statistics were not easily available for other course offerings at different institutions.

ACCREDITATION CRITERIA:

The wide disparity between Building Envelope and Building Science content in Architecture versus Engineering curricula can be easily traced to the accreditation rules for the two disciplines. Architectural criteria, as outlined below, include direct references to building envelope systems and related technologies, in multiple locations throughout their guidelines. A program cannot completely fail to teach in this area if they wish to retain their accredited status. However, it can also be seen that such criteria do not result in a uniform treatment of the material in all schools, considering that all listed in Table 1 are accredited (with the exception of Ryerson University, which is not a professional program at this point in time), and the courses vary from a general building construction concentration, through a combination of the two areas, and ultimately to a

concentration of building science focus as the means to teach general construction issues. The depth of discussion might also be seen to relate to the overall duration of the program. Institutions thatoffer a Professional Master of Architecture degree within a three year period, typically have fewer required core technical courses than can be accommodated in programs of a five to six year duration.

Canadian Architectural Accreditation Criteria:

The criteria for determining Architectural Accreditation are set by the Canadian Architectural Certification Board (CACB) and parallel the criteria as set by the National Architectural Accreditation Board (NAAB), which is the governing body in the United States. The Accreditation Criteria for Architectural programs are "outcomes" based. Outcomes based learning poses specific requirements that require the students to develop an "awareness", "understanding" or an "ability" of the criteriain the area in question. This is also known as "performance based" methodology.

"The list of **Performance Criteria** begins with fundamental skills and knowledge, continues with technical skills and knowledge, and concludes with a focus on practice and societal roles. This sequence is intended to foster an integrated approach to learning that cuts across subject categories."[iii]

The system has been revisited and refined over the last decade, increasing the specificity of technical and environmental/sustainable content in the curriculum. The current guidelines date from 1998. Such revisions are driven by the profession, which sees itself as the end consumer of the "product". One of the more recently developed criteria, and one that has had a large impact on the content and direction of the program, has been the requirement for a "Comprehensive Building Design Studio". This type of studio requires the complete integration of the technical knowledge gained in other core courses, into the design of a large building. *This requirement is the only point in the duration of the student's education that requires the integration of technical knowledge into the architectural design process.*

To this end, the inclusion of knowledge in the area of building envelope systems, and potentially building science as well, isrelatively clearly spelled out. Of the 37 points in the guide, the following seven will have the greatest impact upon the amount of teaching in the area of building science and envelope technologies. Others, however, do place importance on related technical issues as well as concerns about professionalism in the design process.

"18. Environmental Systems
Understanding of the basic principles that inform the design of environmental systems, including acoustics, lighting and climate modification systems, and energy use

20. Building envelope systems
Understanding of the basic principles that inform the design of building envelope systems

22. Building systems integration
Ability to assess, select, and integrate structural systems, environmental systems, life-safety systems, building envelope systems, and building service systems into building design

24. Building code compliance

Understanding of the codes, regulations, and standards applicable to a given site and building design project, including occupancy classifications, allowable building heights and areas, allowable construction types, separation requirements, occupancy requirements, means of egress, fire protection, and structure

25. Building materials and assemblies
Understanding of the principles, conventions, standards, applications, and restrictions pertaining to the manufacture and use of construction materials, components, and assemblies

28. Technical documentation
Ability to make technically precise descriptions and documentation of a proposed design for purposes of review and construction

29. Comprehensive design
Ability to produce an architecture project informed by a comprehensive program, from schematic design through the detailed development of programmatic spaces, structural and environmental systems, life-safety provisions, wall sections, and building assemblies, as may be appropriate; and to assess the completed project with respect to the program's design criteria"[iv]

The Accreditation requirements do not place a visible emphasis on any particular area of technical development. Issues of structure and construction appear to be equally weighted. The overall intent of the requirements and the Comprehensive Studio is to produce graduate architects that are capable of properly designing and detailing the building envelope. Where the last two hundred years have seen the roles and responsibilities of the Architect broken down into specializations and parceled off to consultants, the ability to design and detail the envelope is still perceived as being part of the expertise of all practitioners. Generally speaking, the traditional Architectural practice does not tend to hire consultants to assist with the preparation of the contract documents for the envelope, unless they are using a highly specialized skin system such as a double façade.[v]

Canadian Engineering Accreditation Criteria:

The quality and content of Engineering programs in Canada falls under the criteria developed by the Canadian Engineering Accreditation Board (CEAB). Unlike the Architectural Accreditation criteria, this process is not outcomes based. Within the guidelines and requirements, curriculum is to be developed that has a content distribution in the areas defined as: Mathematics, Basic Science, Complementary Studies, Engineering Science, and Engineering Design. There are also proportions within courses to be devoted to lectures versus labs. Each program must achieve defined numbers of credit hours within each subcategory. Within the categories of Engineering Science or Engineering Design, in which one might expect building envelope scienceto be addressed, the guide does not prescribe a set range of compulsory topics for any particular field of Engineering. These are left to the discretion of the varying schools and departments.

CEAB Criteria: Curriculum Content
"The following criteria for curriculum content assure a foundation in mathematics and basic sciences, a broad preparation in engineering sciences and engineering design and an exposure to non-technical subjects that complement the technical aspects of the curriculum. Judgment is applied to both the qualitative and quantitative criteria requirements in each

instance. The CEAB gives sympathetic consideration to departures from these criteria in any case in which it is convinced that well-considered innovation in engineering education is in progress. To satisfy accreditation requirements, an engineering program must include at least a minimum of each of the curriculum components specified in this section."[vi]

Building science and building envelope systems, are subsequently not required subject matter as outlined by the Canadian Engineering Accreditation Board within Civil Engineering, Systems Design, or any of the Engineering disciplines. They *may* be included under the umbrella of "judgment" or "well-considered innovation" if the departments wish to include these areas of study and have faculty available with this type of expertise.

American Engineering Accreditation Criteria:

Although the scope of this study did not include an assessment of American university level programs in Architecture and Engineering, there appeared to be some movement (rumours) regarding the potential modification of the Canadian Engineering Accreditation standards to an outcomes based model, following the changes that have taken place in the American system. This may be seen to have a potential impact in terms of encouraging increased flexibility in Engineering curricula in Canada. U.S. Accreditation requirements were radically modified in 2000 to respond to a decline in enrollment in Engineering programs that was determined to stem from a curriculum that concentrated too much on delivering traditional Engineering subjects as described by the CEAB system, but that failed to tie these together with any practical or hands on experience directly related to the field.

"Educators are hopeful that Baltimore-based ABET's (Accreditation Board for Engineering and Technology) relatively new engineering accreditation standards known as Engineering Criteria 2000 would focus more on learning outcomes than technicalities. The standards, adopted two years ago, were supposed to ensure that engineering graduates actually came away with the skills promised them by respective programs."
Engineering Record News 10/21/2001[vii]

Where the CEAB maintains a formulaic set of requirements that determine the basic levels of math, science and design in the curriculum, the Accreditation Board for Engineering and Technology (ABET) that governs American schools, has adopted a more "outcomes based" set of rules that begin to more broadly address the specific topics required in the Engineering degree. The American system also recognizes programs in "Architectural Engineering", which do not exist at the present time in Canada. Even with this more topic specific type of curriculum descriptor, building science and building envelope systems are not listed in the study requirements.

"ABET PROGRAM CRITERIA FOR ARCHITECTURAL AND SIMILARLY NAMED ENGINEERING PROGRAMS
These program criteria apply to engineering programs including "architectural" and similar modifiers in their titles.
1. Curriculum

The program must demonstrate that graduates have: proficiency in mathematics through differential equations, probability and statistics, calculus-based physics, and general chemistry; proficiency in statics, strength of materials, thermodynamics, fluid mechanics, electric circuits, and engineering economics; proficiency in a minimum of two (2) of the three (3) basic curriculum areas of structures, building mechanical and electrical systems, and construction/construction management; engineering design capabilities in at least two

(2) of the three (3) basic curriculum areas of architectural engineering, and that design has been integrated across the breadth of the program; and an understanding of architectural design and history leading to architectural design that will permit communication, and interaction, with the other design professionals in the execution of building projects.

ABET PROGRAM CRITERIA FOR CIVIL AND SIMILARLY NAMED ENGINEERING PROGRAMS

These program criteria apply to engineering programs including "civil" and similar modifiers in their titles.

1. Curriculum

The program must demonstrate that graduates have: proficiency in mathematics through differential equations, probability and statistics, calculus-based physics, and general chemistry; proficiency in a minimum of four (4) recognized major civil engineering areas; the ability to conduct laboratory experiments and to critically analyze and interpret data in more than one of the recognized major civil engineering areas; the ability to perform civil engineering design by means of design experiences integrated throughout the professional component of the curriculum; and an understanding of professional practice issues such as: procurement of work, bidding versus quality-based selection processes, how the design professionals and the construction professions interact to construct a project, the importance of professional licensure and continuing education, and/or other professional practice issues."[viii]

The ABET Criteria also do not specifically require any instruction in "building science issues" per se. The requirements for "Architectural Engineering" may be at least seen to include a focus on the design of buildings, whereas requirements for Civil Engineering do not include "buildings", and therefore building science studies, in any specific way.

Potential in the Development of a Degree in Architectural Engineering:

The degree of "Architectural Engineering" has the potential to capture and stress the issues of building science and envelope design within a curriculum that simultaneously considers scientific and design issues. The nature of students that enroll in discrete Architecture and Engineering programs is different enough to allow detailed concerns of envelope performance to fall in between the "designer" and the "scientist". The subject matter is too technical for most design oriented Architecture students – the ones with the most access to courses in this subject. It is also not deemed critical enough in the world of Engineering to warrant more than a handful of graduate level courses at institutions where building science engineers are engaged in departments of Civil Engineering. In the end, neither curriculum embraces the topic with a high degree of interest that can result in the development of curricula or programs that graduate students with cutting edge resources.

An specialist practitioner that is competent in the field of building envelope science requires a higher level of scientific knowledge than is normally included in the typical architectural curriculum in order to be able to both understand as well as design and test building envelope systems for a high level of performance. Such performance is further complicated by the wide range of regional and climate based issues that effect the function of the building envelope. The majority of architectural programs do not tend to develop mathematics and physics skills beyond rudimentary studies in statics and strength of materials for use in structural design computations. Chemistry is not a required course for entry to the study of architecture, so

many students would be unprepared to undertake advanced studies in materials sciences, this hindering their ability to design for thermal, moisture and other climate related effects on the building envelope.

Specialist practitioners in building envelope science also require more experience with the design of buildings as architectural elements than is usually discussed in engineering programs. As buildings must not only "perform" but be able to be marketed and contribute to the cultural development of cities, many envelope decisions must also be based on aesthetic and budget considerations that arise from these issues. If engineering based practitioners are not schooled in these areas, their performance based decisions may not be well heard or heeded. Therefore a specialized study in building envelope science needs to be a discipline that is inclusive and holistic in its study of the separate areas of Architecture and Engineering.

At the present time, an accreditable degree in Architectural Engineering is not possible under either the CACB or CEAB Guidelines. Although the performance based outcomes of the CACB Guidelines may permit technical studies to be expanded, this may begin to impinge on the required study time in areas of culture and the general perception of the higher design focus of the traditional degree. At present, the only accreditable degree titles are Bachelor of Architecture and Master of Architecture. From the perspective of the skills marketing of graduates, it would be preferable to hold a degree that announced the building science specialization more obviously.

One of the major barriers to establishing an Architectural Engineering program within the current CEAB requirements would arise from issues in the balance between pure science and mathematics studies, and the higher level of complementary studies and design studios required by an architecturally driven curriculum. One of the supposed outcomes of the movement of our School of Architecture at the University of Waterloo from the Faculty of Environmental Studies to the Faculty of Engineering was to have been the development of a degree in Architectural Engineering. It would have been the first of its kind in Canada, and specifically would have allowed for areas of concentration in the fields of building science, envelope design and more building focused structural design. At this point in time, the CEAB requirements would limit the degree of "architecture, design and cultural studies" in the curriculum as these would need to fit within the narrow slot of "complementary studies" courses. These types of courses need to run from the beginning to the end of the degree in order to allow the development of envelope studies that recognize the broader issues of buildings as Architecture. As the present situation does not allow for the launch of an accreditable program in either discipline, it has been placed on the "back burner" in the interim. This is most unfortunate as such a program has the potential to begin to graduate, cutting edge, research trained, building scientists. The ABET guidelines, however, would permit such a degree.

CONCLUSION:

It would seem that the "professional loop" that feeds on field research and practical implementation, is not being enriched by architectural and engineering graduates that are versed in the detailed fields of building science and building envelope design.

Graduates from professional programs in Architecture are more likely to have a higher working knowledge in designing and detailing the building envelope, but may not be motivated to pursue such a scientific area as a career focus. Such experience and education is generally not a part of the majority of engineering programs, and is not likely to become so, unless accreditation requirements change to allow a more outcomes based assessment of programs.

Notes

For a more detailed description of the course survey, and course descriptions, please visit: http://www.architecture.uwaterloo.ca/faculty_projects/terri/nbec2007/

[i] Accredited Professional Architecture Programs included as listed on the CACB website: http://cacb.ca/index.cfm?Id=2789&M=1357&Sequence_No=2789&Niveau=2&Repertoire_No=660386109&Voir=sections_liste
Ryerson University's four year Architectural Technology degree was also included.

[ii] CEAB Accredited programs in Civil Engineering and in Building Engineering as listed: http://www.ccpe.ca/e/acc_programs_2.cfm

[iii] Canadian Architectural Certification Board Guide to Student Performance Critera, 1998. p. 2

[iv] Canadian Architectural Certification Board Guide to Student Performance Critera, 1998.

[v] Façade consultants were hired for both the CDP in Montreal as well as the CCBR in Toronto, both which included double façade exterior wall systems.

[vi] Information excerpted from the CEAB Accreditation Guide for 2006/2007.

[vii] Schools Seek New Ways to Retain A Most Valuable Asset—Students, Dwindling enrollments are met with new determination 10/21/2002, By Debra K. Rubin and David B. Rosenbaum, with Jonathan Barnes in Pittsburgh, http://enr.ecnext.com/free-scripts/comsite2.pl?page=enr_document&article=feedar021021

[viii] Information taken from the ABET website, Criteria for Accrediting Engineering Programs for 2006/2007: http://www.abet.org/Linked%20Documents-UPDATE/Criteria%20and%20PP/E001%2006-07%20EAC%20Criteria%205-25-06-06.pdf