Beyond Engineering Design: What are the natural boundaries of design education and research for Canadian universities?

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ABSTRACT

Design is a key present and future contributor to the wealth of nations. It is a discipline in the sense that it is a coherent body of thought and practice, but in academia is almost invariably distributed across disciplines concerned with particular kinds of design. Successful design work involves many such disciplines. Contemporary design practice demonstrates work organizations in which no one discipline has privilege of priority. Several trends, including globalization, environmental limits, multiple clients and criteria, limited disciplinary perspectives, design tools, collaboration, disruptive technologies and changing patterns of design education point to an increasing scope both for the act of design in society and of the disciplines that must effectively interact on design problems. An implication is a need for a corresponding increase in communication and collaboration across all relevant design disciplines.

1. INTRODUCTION

Worldwide, engineering and design schools have had to accommodate an increasingly complex world. Technology is becoming both more complex of itself and is embedded in more complex ways into society. As the planet approaches natural limits of resources and population, design must also deal much more thoroughly with the externalities¹ it creates. It seems very clear that prior disciplinary boundaries work against success in complex design situations. Worldwide, several engineering and design schools have developed aspects of their programs to deal with

the social, technological and process complexities that so characterize contemporary design. For example, Carnegie Mellon University's history of design research and education spans five of its colleges, nearly thirty years, several large centres (DRC, EDRC, ICES) and has spawned a related department (Engineering and Public Policy). CDEN represents a remarkable, and remarkably ambitious, national program of this kind. Its main aim appears to be

to promote the development and the sharing of educational engineering design tools among all Engineering Schools within Canadian Universities. (CDEN website[1])

Few would argue about the importance of this aim to society or about the early success that CDEN is achieving in its efforts. The solution is a good one, but is the problem understood? Contemporary design work is a nexus of finance, policy, business process, client relations, invention across many disciplines, engineering, marketing, sales and evaluation. Its success depends on many disciplines and one of the greatest sources of design failure is failure of interdisciplinary communication and collaboration. This impacts the CDEN effort in at least two ways. First, can the CDEN mission "to create initiatives which strengthen the design engineering community and promote innovation"[2] be fully realized with the network's current strategy of including other design disciplines as adjuncts to the NSERC Chairs in Design Engineering? Second, is the appropriate national goal the improvement of engineering design, or the improvement of the entire design enterprise? This paper presents an argument that places CDEN as a critical part of a larger enterprise and makes positive suggestions for how engineering and other

¹ Used in the sense of an effect of an economic process on parties external to the process.

design disciplines can work together towards better outcomes across design education as a whole.

2. CONTEXT

Everyone designs who devises courses of action aimed at changing existing situations into preferred ones. (H.A. Simon [3], p.129)

Few today would contest that the design of any complex system necessarily involves multiple players. Yet this was not always so. For instance, in many architecture schools of less than a generation ago students learned that architects were the overall project designers and were served by the technical expertise of engineers. Thankfully, this arrogant viewpoint has not withstood the test of time. Today the reality of building design projects is that multiple acknowledged designers must work together to achieve a good building. Architecture is only one of the professions that may take a leading role. For example, in hospital design, the programmer (the person or persons who establish the design brief) plays a large role in and may actually lead the design process. Design projects are understood as hierarchies, with design work being done at every level of the hierarchy and with the relations between levels in the hierarchy being a major source of process complexity. Parochial attitudes do persist in the various design disciplines, but thankfully are under siege from reality: all design disciplines involved in a project may be critical to success. There are many forces that promote this inclusive stance. Knowing that we are preaching to those that are both converted and sophisticated, we provide the barest of sketches for each below. Our intention is to argue that all forces align towards greater complexity for design. The forces at play are: globalization, environment, multiple clients, limited perspective, design tools, collaboration, and education. These are presented below.

Globalization

The oft-used word *globalization* identifies a large set of phenomena that affect the entire world. For instance, Friedman [4] (p.23) identifies at least six major facets (and forces) in globalization: financial markets, politics, culture, national security, technology and environment. Each of these is a source of complexity for design projects. From a supply perspective, even something as “local” as a building is now often designed and delivered by teams of firms whose members come from many nations. Taking a demand perspective shows a magnification of both global and local effects. Objects such as the Apple iPod are released simultaneously into markets worldwide, yet are

localized to those markets in many ways. More specific designs such as motorcars and mining operations may be intensely adapted to local context. Globalization creates both commodity labour markets (draftspersons and computer programmers in India), and specialized niches (stone cutting in Italy). Each increases the complexity of design business and process.

For developed nations globalization increases the value of knowledge services such as design. In a global economy where comparative advantage determines the allocation of capital and operations, developed nations have little to trade on other than the education and knowledge of their citizens. Design, by transforming ideas into useful products and services, is a crucial part of Canada’s future.

Environmental limits

There can be little doubt that humanity’s unintended effects on the environment are becoming more important and more complex. Terms such as *sustainability* connote the important design end of controlling such effects. What is clear is that effects are neither fully known nor knowable in advance. Designers must deal with known effects in current projects, balancing them against scientific predictions of future effects. The scientific predictions themselves change over time, requiring the designer to adapt and revise design solutions. Current and future effects both point to increased complexity in design and increased expertise that must be brought to bear on design problems.

Multiple “clients” – the reality of multiple criteria

Each design discipline is prone to the dual conceit that it understands the scope and importance of its domain. Consider, as admittedly caricatured positions, the structural engineer who provides safe and economical building structures, the interaction designer who creates the end-user experience of an MP3 player and the architect who designs a new university building. They are all parts of a multi-use complex. For each, normally exogenous criteria may actually be the determinants of project success. If the structural engineer is engaged in the design of a roof over the British Museum courtyard, then project scope must expand to the visual reception of the structure. The MP3 player interface design, however sophisticated, may gain no footing if the company’s market researchers have misread a trend to combined cell-phones and MP3 players. The university architect may find his or her exquisite design built but unused due to an error in project politics and finance.

The reality of design is one of multiple “clients” and criteria. While a project may have one client in legal terms, it may have dozens of “clients” for which a failure to respond may doom the project. Each of these clients may be concerned with multiple and conflicting issues. Bringing appropriate expertise to bear on these issues requires more than just *engineering* design expertise. The management of the participants needed to integrate the expertise in an effective and cost-efficient way is another source of complexity.

Limited perspective

Herbert Simon and others [3][5] argued that achieving recognized expertise must be measured relative to the span of human life. It takes at least 10 years of study to become an expert in anything, simply because expertise is measured relative to others who are spending their (usually youthful) years acquiring comparative expertise. Ten years is not long when measured against the knowledge we would like to acquire. An inevitable result is specialization and the limited viewpoints that such must imply. Design does have concepts that apply across its sub-domains, but each domain has key concepts and artifacts that simply take time to master. Chemical engineering has the process flowsheet, electrical engineering the study of signals and circuits, architecture the organization of form, space and material. Each is crucial to the design problems to which it applies. Design must produce multifunctional systems from a basis of limited, often single-function, viewpoints.

This motivates the need for design generalists, able to work effectively in diverse environments for the sake of knitting together the work of design specialists.

Design tools

Design work is transiting to extensive use of digital media and computer-based tools. This has profound effects on both design work itself and the products of that work. For instance, fabrication technology enables the largely automatic manufacture and rapid assembly of products composed of many custom pieces. Design practice is seeing new accounts of design processes, new levels of prediction of design performance, new systems for designers, and new forms of design that are enabled by digital media and fabrication. Finding a dynamic balance between the intensive use of digital media and computer-based tools on the one hand and the cognitive processes that are fundamental to designing is an ongoing issue not just for practitioners (and so educators too), but also for design researchers.

These digital tools allow designs that were not possible before. For instance, in architecture, the Guggenheim Museum in Bilbao with its curved shapes could not have been built without the digital media. Neither could the (much more restrained) roof of the British Museum courtyard. In such schemes digital data are not limited to design, but are transferred between architects, structural engineers, and fabricators.

Collaboration.

In a complex world of multiple criteria and limited perspectives, there is no master builder. Vision can and does come from any quarter. So does direction – design projects vary tremendously in how they are organized as processes. This puts a high premium on teamwork and collaboration in design, particularly within teams in which members have distinct viewpoints and may have little common conceptual ground.

Design does have generic knowledge – there is much in common in design work across disciplines. Shared experience and process can be important glue in holding together the parts of team. Clearly identifying and expressing this generic knowledge is an open design research issue, but also impacts significantly on design education as it forms the foundation for integrating design education across disciplinary “silos”.

Disruptive technologies

Technology often finds application outside the sphere in which it was invented. To the receiving sphere this can present as disruption. To IBM, the PC was hugely disruptive – it largely displaced IBM’s mainstay product line, the mainframe computer. To design, disruption presents as unpredictable change, both the project outcomes and design expertise that must be brought to bear. While disruptive technologies often lead to new arguably improved situations (consider the world without PCs), too much disruptive innovation will undermine economic viability. Balancing innovation through disruptive technologies against the stability of the technological status quo introduces another kind of complexity to the design endeavor.

Education

Each of the above factors is well known. Each points in the same direction – to complexity of design practice and diversity in design teams. Further, it seems likely that a wider range of graduates will be called upon to play design roles in their careers.

In some design schools there is a tendency to separate design research and practice into separate categories. The argument goes that bringing practitioners into teaching roles in the school will enrich students' experience and better prepare them for practice. With few exceptions, such practitioners find themselves marginal to the main (and tenure-granting) stream of intellectual activity in a school: research. In short, school structure militates against inclusion of practice in the long run. The reality is that high quality outcomes follow from both practice and research. An implication is a need for academics whom are leaders in design research. Of course, this simply recapitulates Simon's book-length argument [3] for developing a true science of the artificial as a basis for engineering schools. We note that Simon's strategy is somewhat different from the largely educational focus taken by CDEN. Simon advocated a programme to establish what he called a *science of the artificial* that would sustain design as a first class category in the academic disciplinary hierarchy.

Diversity of scope, expertise, interest and argument will be a feature of the design education and research picture in Canada and elsewhere for some time. From national economic and social perspectives each discipline delivers important outcomes. Given the context above there is a clear premium on explicit collaboration and design model sharing. The natural scope of design in Canadian universities includes many disciplines and both research, education and practice.

3. CASES

We describe three cases that demonstrate how distinct design domains are distributed across areas of expertise, education and professional organization.

User interface design

The May/June 2005 issue of the professional magazine ACM Interactions was devoted to a discussion of who owns the so-called *user experience*. The first sentence of the editor's introduction captures the implicit conclusion of the series of short articles comprising the issue.

This issue of <interactions> addresses the current "controversy" over who owns the user experience (UX). But is that a legitimate question or just a straw man? Can any one person or profession own UX? (P. Gabriel-Petit [6])

Authors of the twelve articles include business owners (prescription: make executives and business leaders aware of the value of user experience); team

leaders (good internal collaboration is essential); a *Chief Experience Officer* (leadership can come from any area of expertise); designers (position yourself within your organization); user interface managers (perfect your design process); a very senior inventor/consultant (the engineers control projects – we designers can win power by political organization); an *interaction designer* (we own user experience and need to work to get recognition for this fact); an *information architect* (focus on the problem to solve and bring all necessary resources into play); a technical writer (work in concert with others to deliver effective communication); a *usability engineer* (have a methodological design approach and bring in needed resources); and representatives from a user experience meta-organization (www.uxnet.org [7]) (network and understand each other). The experience of the user has become critical in many design problems, but remains only one of many issues that must be resolved in a successful design. Even so, it is clear that there are many relevant areas of expertise that must be brought to bear on this single issue, and that design processes reward successful communication, collaboration and management.

Sustainability in Building Design

Sustainability labels a complex of criteria all of which have increased in importance due to resource limitations and environmental effects. The goal of so-called *sustainable design* is to create design outcomes that limit or solve current and future environmental problems. As a concept, sustainability suffers from both breadth and lack of clarity. The concept necessarily addresses multiple design criteria and thus brings all of the intellectual issues of multi-criteria decision making and the professional difficulties of multiple required sources of expertise. It remains an unclear problem, less because of muddled thinking than because of the state of scientific knowledge of possible environmental effects. Research agendas into sustainability typically include collaboration, multi-criteria decision making, digital representation and scientific study of the effects of design decisions. Many design schools have courses or other taught content on sustainability. Each design discipline addresses the issue in its own way, and organizations exist, such as the Canada Green Building Council (CaGBC) (www.cagbc.org [8], which is a "broad-based coalition of representatives from different segments of the design and building industry." [9]. The CaGBC has adapted the US-based LEED rating system (Leadership in Energy and Environmental Design) for the Canadian context. Interestingly in the context of a discussion on multidisciplinarity in design, this rating scheme is

consensus-based. It provides weightings across five credit categories, each of which is typically handled by a separate area of professional expertise: sustainable sites, indoor environmental quality, materials and resources, energy and atmosphere and water efficiency.

A key issue for architectural schools (and perhaps for other design disciplines in building, such as building engineering) remains that the standard scope of the curriculum is inadequate to effectively address the issues of sustainability. This is a problem of both space and educational opportunity in the curriculum. Without significant involvement of other design perspectives, it is hard to model a design process that leads to effective sustainable outcomes, yet it is just such process modelling that is one of the core arguments on which project-based (studio in architecture terms) education stands.

The NSERC Design Engineering Chair at the University of Manitoba

A caveat. In this section we profile the activities of the NSERC Design Engineering Chair (Ron Britton) at the University of Manitoba entirely from a perspective outside of the chair-holder's department. We do this because the external view is that the NSERC Chair is making a positive difference to design education outside of engineering (in addition to its mandate within engineering) and thus presents an argument that the natural scope for design education extends beyond a single unit.

At the University of Manitoba, the NSERC Design Engineering Chair has generated a significant change in the role of the architect with respect to engineering, technology and industry. It has done so through its engineers-in-residence program, through facilitating industrial contacts and through access to Chair facilities.

The Faculty of Architecture has regarded the NSERC chair as both an important and necessary conduit to the engineering discipline and as a significant influence on the institution's ambitions in design education and research. While the NSERC chair often acts in the capacity of informal consultancy he has served as an important member of faculty and administrative searches.

More recently, the NSERC chair has played a key role in the development of the future joint Architecture/Engineering M.Des and D.Des degree programs. This joint collaboration is a reflection of an evolving pattern of mutual influence. While the NSERC chair is gaining an insight into the design strategy of architecture studios, the architecture program is developing a significant shift in its

approach to industry and technology. The shift is towards concrete realization of design ideas.

Architectural education and research has traditionally placed a high value on imagination, generation of ideas and broad understanding of design situations. Architects often use the terms "experimentation" in the sense of making multiple design proposals for subsequent critique and "indeterminacy" to label an imprecise fit between a design and the problem it putatively addresses. The term "studio" can be thought of as a synonym for "project course".

"Experimentation" and "indeterminacy" play a fundamental role in the way that architects develop teaching and research agendas. Often technology is seen as a tool, to be played with in a free form manner without a specific agenda. In encounter with the more formal world of engineering design, such open and playful uses of technology seem to provide a wide breadth of ideas and approaches. For architecture, engineering design provides the important imperative to make things "work".

The school of architecture has developed studio based research workshops around a series of industry, design and technology themes. It currently offers these workshops in advanced product design, fabric formwork structural concrete and digital manufacturing technology.

These semester length workshops are built around deceptively simple objectives: make a beam, create a wall membrane or make a chair. The key is that each workshop promotes the free and liberal exploitation of usually restrictive or traditionally complex technologies. As an example, students are given liberal access to a CNC laser cutter and are encouraged to experiment and produce as many analogies of real projects as possible. The emphasis is placed on design and experimentation above problem resolution. Following this playful stage is an intensive period of analysis and post rationalization of the artifacts that are produced: A re-conception rather than a preconception, if you will.

Students develop an intuitive familiarity with technology to the extent that the traditional engineering principles of theory, calculation and precision are logical (although difficult) extensions of a creative process. The moment diagram of a structural beam, for instance, is now a mathematical and graphic confirmation of what they have mastered intuitively. This inversion of the traditional design process (which proceeds from idea to concrete technical realization), opens the door to an iterative feedback loop that can include the active participation of engineers, technologists and

industrial partners. In fact, the terminal phase of these workshops are usually completed with the production of a real prototype in an industrial context at the full scale; fabric formwork beams are cast at full scale at two local concrete factories; furniture prototypes are built in a local factory using the actual industrial equipment with the full participation of the industrial partners.

This approach is mirrored by the researching faculty at the U of M. Many faculty research agendas begin with a speculative or experimental approach to design research. While the work is initiated through a relatively indeterminate process, the industrial and technical grounding of this work results in a set of focused engineering and industrial problems.²

Climate Engineering

A firm of specialists concerned with climate engineering is Transsolar in Germany headed by Mathias Schuler. The firm's focus is on collaborating with architects to design buildings for internal comfort on the basis of local conditions such as climate and construction methods. The firm bases its ideas on the fundamental principles of physics and thus is able to approach problems of greatly varying conditions. The firm consists of specialized experts: It sees itself as one of several firms of specialized experts collaborating with architects as integral partners from the earliest conceptual stages of design. This is such a logical way to collaborate that one wonders why architects, in spite of the interdisciplinary education they receive, do not usually adopt this collaborative mode. Instead architects often bring in specialists to try to repair designs too far advanced for a real integration of multidisciplinary concepts. Perhaps the ethos of the solo, star architect as artist is to blame. Mathias Schuler says [10]

We see ourselves as co-writers within a network of planning [design] partners who inspire each other mutually and whose basic reciprocal understanding keeps friction during the collaboration process to a minimum.

² The University of Manitoba case demonstrates a long-standing feature of architectural research. Like engineering, it is applied. Perhaps distinct from engineering is the degree to which practical validation is an integral part of architectural research. Such validation tends to occur in unique cases, just as most buildings are constructed as unique cases. In the academic discipline of architecture, the repeated deployment and post-facto evaluation of ideas in practice often receives considerable recognition in academic evaluation processes.

Werner Sobek, who has collaborated with Schuler says [10]

The skillful realization of a work of architecture in all its intricacy, complexity, and multi-functionality has long since outgrown the capabilities of a single person.

Helmut Jahn, who has been a major client of Transsolar, explains his work with Mathias Schuler in the following terms [10]:

As a physicist he approached environmental engineering informed by science using minimal equipment, maximizing natural resources and increasing the comfort in buildings....Today as far as circumstances allow we do all buildings together. We think alike, are aware of the other's discipline and in the course of discussion and exploration we cross over into the other's field. Architect and engineer speak the same language. We have coined the phrase "Archi-Neering" to describe this working relationship.

4. FOR CDEN

We make no argument with CDEN. In our view, it and the NSERC Design Engineering Chairs are providing critical and capable service to Canadian education and society. As far as we are aware, CDEN is the most serious and positive effort worldwide in bringing design into the engineering curriculum.

We do contend though that, to be most effective in the complex world of contemporary design, the national interest is served by a broadening of the scope of design education and research that CDEN presents. Whether CDEN, as the most visible group in design education in Canada so broadens is, in a sense, immaterial. What is important is that all design disciplines (each of which contributes to Canadian design industries) contribute to and gain from an education that grounds students in the realities of global, multidisciplinary, digitally mediated design practice and production. Such is more likely to be accomplished by the equal involvement of all design disciplines, not just those that have the label "engineering" in their names. We argue on grounds of education, research and faculty career development.

Education

CDEN would better fulfill its (largely educational) mission by building strong relations with others interested in design education. Design engineers constitute a relatively small proportion of engineering academics. This lack of "critical mass" may be a result of a simple lack of personnel or of the

geographical dispersion of personnel. In any event, one way to increase the number of people involved in CDEN is to proactively pursue connections with other organizations involved in design education, even if those organizations are not engineering organizations.

Some obvious organizations are the American Society for Engineering Education (<http://www.asee.org> [11]), and the Design Exchange located in Toronto (<http://www.dx.org> [12]), but there are others. The Interior Designers of Canada (<http://www.interiordesigncanada.org> [13]) promotes quality education through an approval process.

Also, there exists the CDIO (Conceive, Design, Implement, Operate) Initiative (<http://www.cdio.org> [14]), an international framework for engineering education that is developing educational elements for a complete curriculum. Two Canadian engineering schools are already members of CDIO. Other related groups include Universal Design Education Online (<http://www.udeducation.org> [15]), the Interior Design Educators Council (<http://www.idec.org> [16]), the UK Design Council (<http://www.designcouncil.info> [17]) and of course the Design Society (<http://www.designsociety.org> [18]).

Research

CDEN would better fulfill its mission by greater advocacy for design research. There are clear benefits to the agenda of having tenured faculty who are recognized for their expert knowledge and international standing in design research. However, Canadian design researchers currently lack a “community” to facilitate collaboration and building the same “critical mass” that CDEN seeks to achieve for design educators.

CDEN was originally conceived to include research groups, but that element has yet to mature. Perhaps there are other ways of promoting this kind of activity. Developing a design research community would be beneficial for CDEN because the work of such a group would naturally lead to a more robust understanding of design methods and philosophy. Such an understanding could be leveraged by CDEN to develop better educational materials. Also, a design research community working separately but in collaboration with CDEN could help focus CDEN’s energies and resources.

We have argued that complexity in design will continue to be a key factor. A design research community could provide valuable input to the management of this complexity, again relieving CDEN educators of some of this work and helping to

keep the CDEN community current with academic knowledge. The issues discussed in the opening sections of this paper are all issues with both important research features and significant educational impact. The work of a design research community on these matters should facilitate the development of better curriculum and content for design education.

There is demand for an improved design research community across design disciplines (including engineering). For instance, a group of researchers primarily from architecture, landscape architecture, urban design, and industrial design have been meeting under the informal rubric of the Canadian Design Research Network. This group, like CDEN, is hindered by its scope of expertise. Design research within domains shows both significant commonalities and differences across domains. Research on commonalities increases the explanatory power of results. Researchers who are aware of the distinct methods of other disciplines are more likely to be able to adapt external methods to their own design domain. Design research across domains reveals the need for improved models for multi-criteria decision making, scientific prediction of consequential effects of design decisions and management of complex group processes.

Faculty career development

Over the last generation research on design has achieved a level of credibility in the academic community. There are several design-related journals, for instance, Research in Engineering Design, Artificial Intelligence in Engineering Design and Manufacturing, Information Technology in Construction, Computer Aided Design, Design Studies, and The Journal of Engineering Design. Faculty specializing in design research have achieved tenure at institutions such as Cambridge, Carnegie Mellon, MIT and Stanford, not to mention several Canadian universities. Most have done so by the classical route of developing a body of robust and at least semi-formalizable work on the act of design, its digital media, the organization of design and (or) design outcomes. In the life of a university department, where resource decisions often depends on strength of argument and character such tenured faculty are crucial in advancing the cause of design in the disciplines. Is CDEN, in its (admittedly needed and important) focus on undergraduate education augmenting the development of an academic culture of design? We do not know the answer to this question but can point out a common and unhealthy pattern in architecture schools where there all-too-

often arises a distinction between so-called research and design faculty.

5. SUMMARY

Design “belongs” to all of its disciplines. Arguments otherwise risk being parochial. Efforts to improve design within disciplines, such as design engineering, are important, even essential to the disciplines and to national society and economy. However, the breadth and complexity of contemporary design argue for an expanded national agenda for education and research.

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