ENGINEERS

Lina Martinsson Achi, *Architect AA MA, KTH MArch*
Industrial Doctorate candidate, Tyréns AB
Visiting Faculty, KTH School of Architecture and the Built Environment
Department of Architectural Technology
Östermalmsgatan 26, SE-100 44 Stockholm
lina.martinsson.achi@arch.kth.se

The Power of Two (or more)*: An interdisciplinary approach to disciplinary excellence*

Science progresses best when observations force us to alter our preconceptions. Vera Rubin

Abstract
In this paper I will talk out of my personal vantage point, and ultimately- belief, in the value of education and research in the face of contemporary, global challenges and competition, and an ever increasing pace of technological development. Through constantly maintaining an educated, critical point of view of the tasks as well as means at hand, one is able to adapt, survive and even thrive. I will address the increasingly more critical relation between technology and innovation, and suggest how collaboration across disciplines as well as between academia and industry may allow one to capitalise from this relation, and to develop a cutting-edge position, and 'reinvent' one's professional position, profile, and skills according to need. I will draw upon examples from my own work: I am currently pursuing complementary roles, tasks and objectives within academia and industry, and in doing so, I am striving to integrate knowledge, resources and concepts from multiple disciplines in order to inform and expand the architectural investigation. One of these tasks is an industrial doctorate project, which is set up as a collaboration between Tyréns engineering firm, KTH School of Architecture and the Built Environment, and KTH School of Engineering Sciences. Within the scope of this project, I am evaluating the impact of morphology on force distribution-patterns, as a strategy to address – evaluate and classify – the structural capacity of a system. I will employ this understanding as a basis for (1) the development of a new taxonomy of structure, and (2) in order to re-address and provide a better understanding of the concept of robustness (that is to say- the capacity of a system to respond to unanticipated load scenarios). Such an approach has got the potential to facilitate early, conceptual structural design development, and may in turn improve the collaboration between architect and structural engineer.

Keywords: interdisciplinary work within academia and industry, technological trends and paradigms, value of education and research, problems and prerequisites of interdisciplinary collaboration, information versus knowledge

Introduction: A Definition of Power

You may detect a 'professional anxiety' within the AEC community. A state of mind which is shared by students, educators, researcher, practitioners alike, and that is the natural result of the pressure exerted by the increasingly more difficult equation (amount of) time + (complexity of) task, resulting in ever increasing professional requirements. And paradoxically, technology appears to make this equation more stressful to relate to, since it appears as if certain areas of knowledge, experience and expertise are rendered obsolete increasingly fast. Whereas before it might have been OK to adopt a 'laissez-faire' approach to one's professional endeavours, today that is not (well, it should not be) a matter of personal attitude or choice. There is an urgent need for professional conviction and excellence. To express it bluntly: we are all doomed as a result of each other's inabilities to act in a professional and efficient manner. A realisation that in itself easily could result in a state of professional paralysis. However, if you just raise your gaze and look around, you may find solace and guidance in the many interesting and inspiring examples of *How To* strive for professional excellence- making efficient as well as creative use of the ever increasing technological power available, through a collaborative set-up, working across disciplinary boundaries. In essence, these educative examples are capitalising from the powerful results of *exponentiation* (expressed as x^a [1]). They adopt an interdisciplinary approach as a strategy to survive in an ever more 'Darwinistic' professional climate. In doing so, they give testimony to the power of exponentiation in different ways, exploiting the 'power of many' in relation to resources, skills, technology, and even design concepts, processes and solutions. In his book *The Medici Effect*, Frans Johansson explains that *when you connect two separate fields, you also set off an exponential increase of unique concept combinations, a veritable explosion of ideas.* [2] He furthermore describes the important relation between quantity and quality, which further intensifies this explosive development. Not only does an exponential increase in itself result in an ever expanding solution space, but due to this productivity (measured qualitatively as well as quantitatively), these set-ups tend to attract attention and hereby, gain momentum through access to an ever larger pool of resources and an ever increased solution space. The successful contemporary examples that profit from these exponential, synergetic effects capitalise from the very same mechanisms that currently cause so much stress to many of their peers. Interdisciplinary initiatives profiting from an exponential mechanism may be found both within academia and industry, and may serve as informative examples of 'dos' and 'donts'. The pitfalls are many, but so is the potential gain. Perhaps most importantly, the interdisciplinary endeavour forces us to scrutinise and refine our working methods, to communicate our intentions in as clear and unambiguous terms as possible. It requires the development of new work processes, it prompts new solutions. And as a result, it fosters education and innovation. It obliges us to state and nurture our core professional skills, so that they are simultaneously exclusive from but at the same time compatible with other, related skills. And in the process, we might begin to relax from the realisation that these core skills are in fact not subject to constant, exponential change. Consequently, we may relate to the fast technological pace in a sounder, more strategic manner, and begin to act more informed and selectively. The 'power of two' is released when we together work towards professional excellence, making innovative and informed use of the technological resources available. Below, I will attempt at further describing this current, potent state of flux, and to account for important findings and indicative trends. I will conclude with examples from my own interdisciplinary pursuits connecting academia and industry.

Processing and Thinking Power

In his book *The Singularity is Near*, Ray Kurzweil discusses the impact and significance of exponential trends for technological development across a wide range of disciplinary fields [3]. He suggests that there are various types of intelligence- of the 'human' and 'machine' kind- and he proposes how to make more efficient, as well as complimentary use of both. He hereby suggests how the 'power of two' ought to combine the synergetic strengths of different types of capacity- essentially, how to link *processing* and *thinking* power. He furthermore distinguishes between technical *capacity* and technical *innovation*, making the interesting observation that *the rate of paradigm shift (technical innovation) is accelerating, right now doubling every decade,* whereas *the*

[1] *A power is an exponent to which a given quantity is raised. The expression* x^a *is therefore known as 'x to the ath power.'* *Wolfram MathWorld* web site, http://mathworld.wolfram.com/Power.html

[2] Johansson, Frans, The Medici Effect- Breakthrough Insights at the Intersection of Ideas, Concepts and Cultures (2004, Harvard Business Press)

[3] Kurzweil, Ray, The Singularity is Near- when humans transcends biology (*2005, Penguin Books*)

power (price-performance, speed, capacity, and bandwidth) of information technologies is growing exponentially at an ever faster pace, now doubling about every year. This distinction between varying types and speeds of progress is interesting, in that it contains two meaningful ways to relate to technological mastery- one *quantitative* and one *qualitative*. It appears as if up until now, the focus within the AEC community has been largely on the first type of proficiency- perhaps not as much by any active, informed choice, but rather resulting from the part awe, part angst provoked by the rapid pace of development and a desperate attempt to 'keep up with the latest'- with implications for both the design output and process. This is manifest in the many 'BLObs' and intricate data flows of our time. And perhaps again resulting from a general feeling of exhaustion, we have reached a point when we simply cannot keep up, forcing us to instead think of different, more creative ways to employ technology. We are beginning to address technology from the point of view of innovation and qualitative application. There is currently a lively debate within academia as well as industry that reflects these two different approaches to technology- essentially further making the important distinction between *information* and *knowledge.* In his article *Do Computers Dumb Down Math Education?*, Jon McLoone of Wolfram Research suggests how a successful 'power of two' strategy may in fact enrich the study of a particular subject- for example Mathematics [4]. In line with the earlier remark made by Ray Kurzweil, he suggests that we should make intelligent use of technology as a means to arrive at a greater understanding of the study topic, and that technology may allow us to free up time for knowledge generating activities. A line of reasoning that of course makes equal sense within an academic as well as an industry setting. Conrad Wolfram of Wolfram Research supports this belief. He furthermore outlines what he believes are the primary reasons for an improved conceptual understanding, that would result from a cleverer use of processing power [5]. He argues that *to get a computer maths system to do a computation, one has to specify the problem precisely and be clear what computations are required to get the desired result.* This remark compares with my previous observations regarding the need for clarity (and the beneficial consequences) within an interdisciplinary setting. Wolfram furthermore goes on arguing for a new way to engage with technology- which is more 'experimental' and that allows for a different type of interaction with the task at hand. He says that, through avoiding the specialist knowledge of 'first principles', and instead favouring a more 'open-ended', intuitive approach to the study object, such an approach allows for the informed investigation of 'patterns of behaviour', in turn with beneficial consequences for improved conceptual understanding. He then concludes with saying that the whole education system needs to be remodelled in order to provide the students with the relevant knowledge, tools and support. The same applies within an industry setting. A shift of focus is required, that will allow us to engage with knowledge rather than information generating activities, and that will allow us to more intuitively reflect upon the task at hand- combining knowledge, skills and resources from various specialist fields. And in doing so, we might attempt to improve the situation somewhat- between the varying speeds of progress identified by Kurzweil- and try to position ourselves so that we ripe the maximum intellectual benefits of our current technical capacity. The relentlessness and force of the technological 'wave' is crushing. Those who learn how to master this violent instability may exploit this power as leverage, allowing them to constantly seek the next crest.

Whether you can observe a thing or not depends on the theory which you use. It is the theory which decides what can be observed. Einstein

The Power of Knowledge- of different kinds

Let us once again return to the distinction between *information* and *knowledge* and make an attempt at further describing in what sense an interdisciplinary set-up may help unleash the educative potential of our current tools. Essentially, the greatest asset of an interdisciplinary approach is the power of diversity. Once carefully acknowledged, this presents a means to make informed and creative choices. Considering the collaboration between architect and structural engineer, the most potent difference appears to be their respective concern with design *initiation* versus *evaluation*, and the various tools supporting these complimentary activities. Expressed as an exponential function, you get 'empirical design', or *evidence based design*- where each step of design development also generates knowledge that is being fed back into the design process in order to arrive at cutting-edge solutions. Such a process has got the capacity to translate information into knowledge, and to lend credibility to the worn out phrase 'research by design'. However, in order to turn empirical observations into research, one must actively engage with the iterative (design-analysis) process. This entails a new approach to the core activities: design and analysis. As a starter, they may benefit from being influenced by

[4] *Wolfram* blog, http://blog.wolfram.com/2010/09/27/do-computers-dumb-down-math-education/

[5] Wolfram, Conrad, *The Practical Approach to Maths Education,* http://www.wolfram.com/solutions/highered/usformat.pdf

each other's primary objectives- one being about setting out to develop unprecedented solutions, the other being about reigning in that solution and label it, according to what is already known. How about reversing those objectives, letting them influence one another? That would present us with grounded design, and invention driven analysis. In order to achieve this synergetic exchange, we may start with taking a different approach to our existing tools, and perhaps also explore and even develop new types of 'hybrids'. Engaging with analysis in a more active, creative way, one would start with acknowledging two potential purposes for analysis, which is different from its more traditional usage (to check the feasibility of a design proposal), and herby also activate it in the sense 'intuition support' (allowing the engineer to step outside of his/her comfort zone), and 'knowledge generator' (enabling the formation of new structural theories that in turn may provide the basis for progressive design). This means that analysis goes from being a passive, affirmative activity, to instead becoming educative and possibly also innovative. The user interaction is key here, in that it allows for learning as well as innovation to take place. In fact, both the learning process and the creative potential are furthermore helped by an interdisciplinary exchange. An iterative process may here be compared with an automated optimisation process- the target being structural, or any other type of design optimisation. In an automated process, the user states the context/starting-point and a search function/evaluation criteria, beyond which technology runs its course. In an iterative, interactive process, even though the objective is similar (to arrive at some form of design optimum) the user interaction allows for a greater richness and diversity, in a qualitative as well as quantitative sense. Such a process has got the potential to enable innovation, as well as knowledge gain. This is largely due to the synergetic effect of compatible differences. A computer is deterministic, whereas a human is potentially not. Architects are frequently reasoning differently from structural engineers. An experienced professional interacts and responds in a different way than an inexperienced one. The power lies in the diversity, and more importantly- in an approach that capitalises from these differences. In his article *The future for structural engineers: challenges and opportunities,* William F. Baker of Skidmore, Owings & Merrill argues that *as construction and design processes become increasingly automated, the reduction in human involvement is attended by the need for extra careful human oversight* [6]. He is hereby identifying another important aspect of 'black-box' processes- namely that an increased usage of technology might in fact require an even deeper understanding of the study topic- that would in turn allow you to successfully control and operate the many complex processes in a meaningful manner. Baker here identifies a problematic (largely generational) communication gap that exists both within the field of structural engineering and architecture- between those that are proficient software uses (with little or no work experience) and professionally well-rounded individuals that prefer a 'pen and paper' approach. And as an equally problematic result, the tools within the field are not put to intelligent use- resulting in an unfortunate relation between the amounts of time spent on *information* versus *knowledge* generating activities. And whereas the current usage often-times results in both labour- and data intense models, this does not have to be the case. In fact, analysis tools employed in an active, educative fashion may provide support for inexperienced users, and hereby compensate for his/her lack of experience. The inexperienced user may in turn allow for a shift of focus for the design-analysis process- enabling it to become an *opportunistic*, rather than *deterministic* process. A naive reading may in fact enable new discoveries. All in all, we need to 'activate' the power of technology within the context of education as well as industry, in order to allow ourselves to engage with knowledge generating activities.

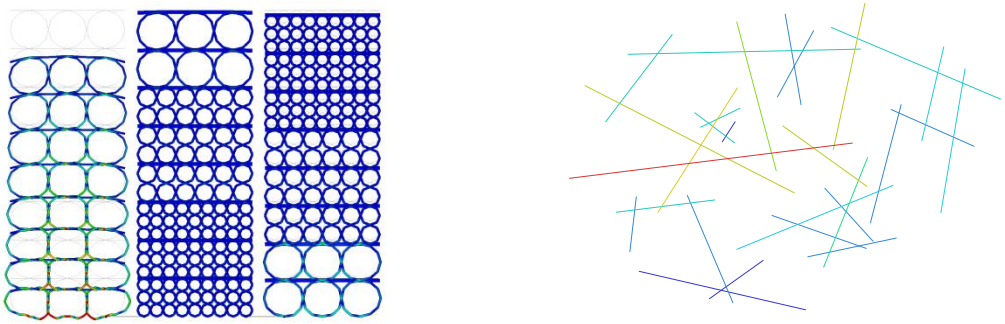

Fig. 1. Indications of morphological 'capacity', measured as axial force (left) and integration rate (right)

[6] Baker, William F., *The future for structural engineers: challenges and opportunities,* article in *The Structural Engineer,* Centenary Issue 21 July 2008

The Power of Gravity- morphology and design equilibrium

In order to further illustrate the points made earlier, I will provide a brief account of my ongoing piece of research, which sets out to both capitalise from and contribute to the rich context of interdisciplinary 'learning by doing'- employing the abundant knowledge and resources available. My Industrial Doctorate research project also sets out to activate the educative potential of technology, in order to deepen the understanding for a specific phenomenon- namely, the structural 'capacity' and 'impact' of morphology- engaging primarily the fields of architecture (at the urban and the building scale) and structural engineering (Fig.1). The main objective of the research is to investigate and further establish the relation between *morphology* and *force distribution*. Morphology is defined as an *intrinsic* geometric property that describes how various parts of a system relate to one another- i.e., the various interrelated 'patterns' of centre lines making up the system. Morphology furthermore has been identified as a purposeful interdisciplinary 'format'- the common denominator that equally engages the architect and the structural engineer.

A brief project summary

WHAT? The development of an alternative approach to structural analysis and classification, based in graph theory (rather than the laws of physics, structural mechanics).

HOW? The adaptation of either (A) specific space syntax (urban analysis method) models and concepts, or (B) specific graph theoretical models and concepts. The development of an abstract analysis approach looking at (a quantification of) morphology in isolation (hereby excluding for example material properties, definitions of cross section and joint type).

WHY? The development of a labour and data economical method for early, conceptual structural analysis will present a means to better understand the impact of morphology on structural behaviour. Such a method would allow for (1) a new approach to structural classification, ultimately informing a new taxonomy for structural systems and sub systems, and (2) a new structural optimisation approach targeting robustness.

The research will contain two stages. The first stage (already initiated) consists of empirical studies of morphology, and precedence studies of selected analysis methods and their core algorithms. These initial studies will then inform a second stage, focusing on methodological (and possibly also software) development. In addition to the study and development of analysis methodologies, the research will continuously contain a parallel strand of theoretical development, with the aim to inform a new body of knowledge that connects morphology and force distribution. The project aims to apply and further develop specific techniques and concepts from the field of graph theory. A methodological as well as theoretical role model is so-called space syntax analysis[7], which has been developed within the field of urban design in order to study the relationship between morphology and flow (of people and cars) in urban systems; also within buildings. The method is being used in order to study and better understand already existing systems, as well as during the design development process. Both of these applications are relevant to my research. I furthermore intend to develop an iterative (design-analysis) method that presents a means for interactive optimisation, according to the educative process described earlier. As an optimization method, my project aims to (A) further illustrate and develop the morphology (versus material or the individual component's) role in the optimization process, and (B) optimize for robustness (i.e., result in systems with high capacity for unforeseen impacts). As a design and analysis method, the project aims to support (both in the sense make more efficient, as well as deepen) the exchange between structural engineer and architect at an early, conceptual design stage, as well as provide support to the individual engineer in his/her studies during a similar, conceptual design stage. In both cases, the project intends to develop the educational potential of an iterative methodology. Based on the main objective- to further inform the understanding of the relation between *morphology* and *flow*- it is furthermore assumed that the research may in fact 'pay back' and contribute to the refinement of tools and concepts within the field of urban design- hereby achieving synergetic benefits all across its interdisciplinary scope. It is assumed that, since a structural system (1) is affected by a non-ambiguous *flow* (gravity), and (2) has got a non-ambiguous boundary condition, it in fact provides a more suitable study object- a less 'noisy' analysis environment- for the investigation of the relation between morphology and flow. The accuracy and relevance of all of the assumptions, concepts and models involved are being continuously evaluated by an international, interdisciplinary network of experts from industry and academia.

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[7] *Space syntax analyses examine the relationships between components of space; each analysis starts with a representation of the spatial components, then makes a graph of these components, and finally analyses this graph using, for the most part, conventional graph theoretical measures.*
Turner, Alasdair, *Depthmap 4- A Researcher's Handbook*, June 2004

Conclusion: The Power of Design (architectural; structural; and other kinds)

This year's IABSE - IASS Joint Annual Symposium that will be given in London in September bears the telling title 'Taller, Longer, Lighter' [8]. The topic for the event is indicative of an important shift of focus for the interdisciplinary collaboration between architect and structural engineer- from extravagant, complicated and lavish (just because you *can*), to sophisticated, holistically optimised design solutions (making intelligent use of our joint resources). This shift has come about as a natural response to the previously mentioned increased pressure on today's designers, and it has triggered several interesting responses to the many complex and urgent tasks at hand. Up until now, I have primarily focused on describing all the exciting possibilities at our disposal. I have not yet given an account for the many *conditioning powers* that make collaboration difficult, and sometimes even impossible. They include: power structures within academia and industry; systems for professional reward and advancement; issues to do with copyright and ownership of data (essentially to do with the complicated issue of *money* versus *knowledge*); obsolete, non-existing or inaccessible technical and 'other' (to collaboration relevant) skills; incompatible concepts, methods and file formats; etc, etc. The primary issue appears to be the one to do with authorship. In the same way that structural equilibrium is achieved by an even distribution of loads, a truly iterative work process aiming towards producing holistic design solutions is characterised by mutual co-dependence. Success is therefore intimately related to the ability to turn the focus away from ownership, and instead bring the task to the fore. We may then gather around this task as *complimentary designers*- each bringing his/her set of skills, limitations and abilities to the table. In this manner, we may help each other defy one another's limited-limiting traditions and insufficient ideas. Given that we are trained differently; we often-times work with different types of evaluation criteria as well as different, at times conflicting design principles; we need to start afresh and together establish the grounds for collaboration in order to find new ways to communicate and exchange ideas. And hopefully, as a positive by-product of the recognition of equal professional worth and co-ownership, we may foster an uninhibited and transparent work environment, with zero prestige and where ideas may flow and flourish freely. And YES- this might produce a new kind of anxiety and identity crisis, as a result of the exceedingly blurred and less-defined professional boundaries; where it is less clear who 'we' are, versus 'they'. I do however believe that this new concern will be rapidly replaced with a sense of fulfilment and renewed confidence and belief in the more broadly defined designer profession. It is nonetheless a true concern at a higher, strategic level- since our existing power structures will be challenged; it will possibly also require a re-structuring of our education system as well as force us to rethink our existing organisation models and the way by which we value different types of disciplinary skills. It is after all not that clear what makes up a future well-rounded professional, and we will simply have to keep at it- educating ourselves and engaging in a productive and all-inclusive dialogue. What is indisputable however is that never before did it seem quite so urgent to be innovative and to excel, in order to strive for equally *elegant* and *optimum* solutions. Never before has *design* been associated with such urgency, whilst at the same time held such rich potency. Design in the sense art *and* science includes creativity and improvisation, as well as rigour and precision. It depends upon strong links between theory and practice. It enables us to challenge and evolve both. It is an utterly enjoyable experience, and one that demands absolute belief in the power of *many*, versus the weakness of *one*. And however unnerving it may be to leave behind the familiar and established- professional identities, work processes and tools, design traditions- it is required in order to enable the next, *joint* step. It is about making a leap of faith, the objective of informed innovation being precisely that- to confidently venture into the rich *Unknown*.

[8] Joint Annual Symposium of the International Association for Bridge and Structural Engineering (IABSE) and the International Association for Shell and Spatial Structures (IASS) , http://www.iabse-iass-2011.com/