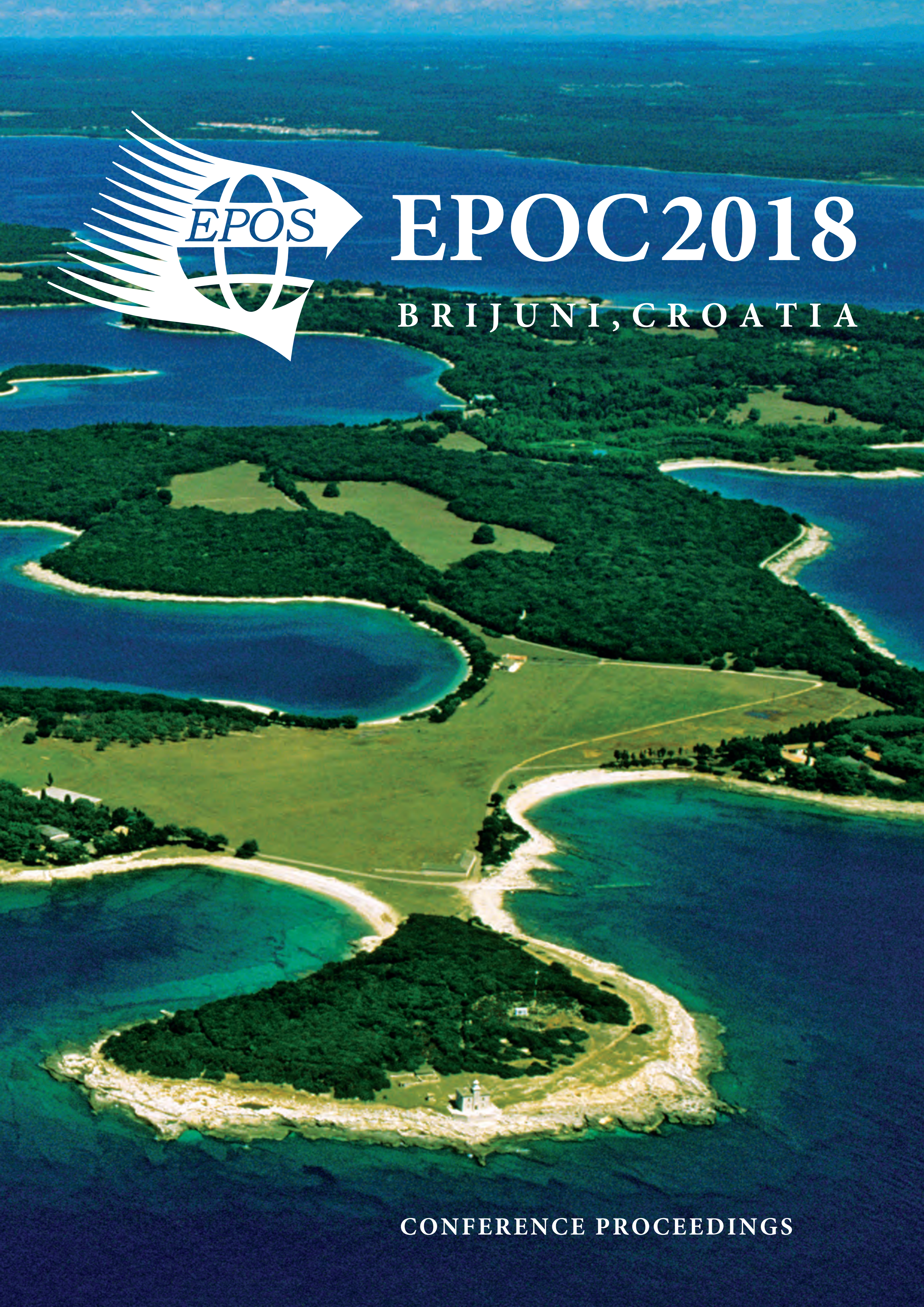

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ABSTRACT

Has building really changed organically, structurally and/or process-wise in North America over the last generation? What happened since the 1990s on the AEC scene? In 1995, Katsanis and Davidson launched a series of five articles entitled "*Horizon 2020*" (H2020) on how the construction industry would evolve over the next 25 years. This was followed by a wave of forecasting articles and public reports appearing in the US, UK, Europe and Australia. Spread over six years, the H2020 series covered critical issues such as "*Building procurement and industry fragmentation - a North American scenario*" (*1996*), "*Design-Build"* (*1998*), "*Network organizations in the AEC Industry*" (*1999*) and "*Professional trends for the professional practice firm and for the building contractor*" (*2001*). This research examines what really happened, whether the forecasts made between 1995 and 2001 were on target and if not, what really took place in building procurement. Two financial crises (*2000 and 2008*) heightened market risk tension and accelerated the industry split into two major segments and risk configuration: the integrated large and multinational (*LME*) firms moving toward servitization and full fiduciary real asset management, while small to medium size enterprises (*SME*) remaining stewards of local construction with greater specialization and wider HR and resource supply chain responsibilities. The findings are based on a thorough review of forecasting literature in building procurement, a series of semi-structured interviews and a risk survey of industry practitioners. All illustrations are from the authors, except for the adapted graphics of Edwards, 1998 and of WEF, 2016.

KEYWORDS: AEC, Construction engineering, Decision making, Fiduciary duty, Environment, Finance, Forecast, Human resources, Infrastructure, Innovation, Integration, Market, PPP, Real asset management, Regulation, Risk, Servitization, Stewardship, Technology.

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> "*As a group, civil engineers typically do not spend enough time thinking about the future. I often asked local members a simple question, ''What is the biggest challenge that civil engineers will face in the year 2008?'' Normally, there was silence and a room filled with bewildered faces… As a group, civil engineers spend too much time on our immediate work… We do not set aside creative time to look over the horizon. Now is a good time to change that habit*."
> – **Daniel S. Turner**, (1998) former ASCE chairman

> *"Since 1998 we could have had a revolution and what we've achieved so far is a bit of improvement."*
> – **Sir John Egan** (*author of Rethinking Construction, 1998*), foreword to the Wolstenholme Report, United Kingdom, 2009

Introduction

Christian Koch attributed the lack of engineers' creativity to the « *Tyranny of projects* », the result of continuous working pressures from structural, organizational, professional and individual sources (*Koch, 2004*). Jeffrey Russel (*Stouffer et al. 2004*) concluded similarly by wondering why the "*perception persists that engineers are uncreative, or worse, do not need to tap into creativity when most engineering projects demand creative or innovative approaches in the design of equipment, systems, and facilities?*" Five years later, Gordon Culp (*2009*) reaffirmed the introverted character of engineers (*Culp, 2009*), which Holly M. Johnson and Amarjit Singh (*1998*) had outlined over a decade before. The ASCE Structural Engineering Institute later reaffirmed this finding by underlining that such self-direction – which supports creativity (*Rice, 2006*) – is one of the soft skills that should be developed by future structural engineers (*Damci et al. 2017*).

Radical changes were facing engineering management and projects over that same period. The growing productivity and constraining issues facing civil engineering gave way to a wide range of research papers on the future, vision and challenges of the industry since the Great Financial Crisis of 2008 (*ASCE, 2006; Boston Consulting Group (BCG), 2016; GFC- Ibbs, 2003*; *Bin Ibrahim et al., 2010; Peterson, 2006; Russell, 2013; Toor & Ofori, 2008; Zawawi, 2016*). This leads us to question: if creativity did not stem from within or amongst the engineers' community, where did the real pressure points come from to explain the challenges and some of the innovation that has transformed the industry?

Based on extant literature over the last fifty years, we found reciprocal forces that influenced and continue to influence and reshape engineering firms around the world. Those forces are driving the infrastructure and urban development (*IU*) industry with an annual turnover of nearly $10 trillion and 6% of the world's Gross Domestic Product (*WEF, 2018*). But even there, "a case can be made for the sector accounting for almost 20% of GDP rather than the 6-7% GDP … [representing] construction output alone" according to Wolstenholme (2009), if the "built environment sector covers the planning, design, manufacture and assembly/construction and commissioning of built facilities [*and*] their subsequent operation, maintenance, refurbishment, deconstruction and re-use". Construction 2020 from Australia estimates "that the actual contribution of the construction cluster was roughly double the standard figure, accounting for 14% of GDP" (*CRCCI, 2004*)

Design professionals are expected to expand at 2.71% over the period, the second fastest growth after computer and mathematical jobs, compared to management (*0.97%*) and finance (*0.70%*) (*WEF, 2016*), while the demand for civil engineers in the US is projected to grow 11% from 2016 to 2026 (*US BLS, 2018*).

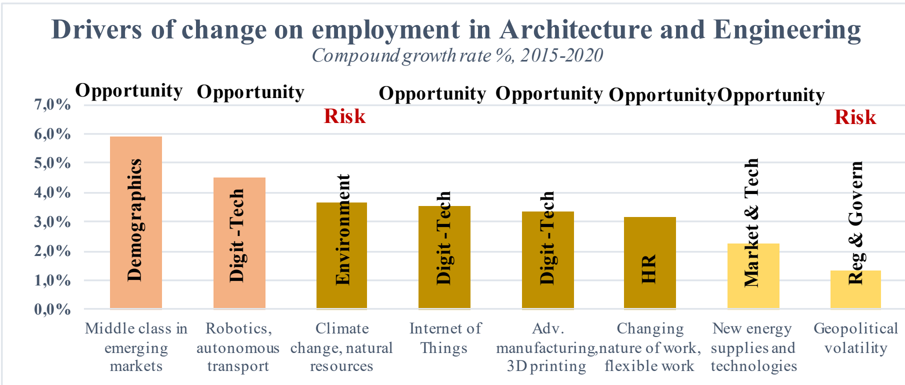


Figure 1: A World Economic Forum survey of human resource professionals from 371 companies from 13 countries and two major regions (*East Asia and Gulf*) is a source to derive our six major pressure points that most likely affected the AEC industry since 1990. Source: WEF, 2016

With such trends as a reference point and the dynamics of the system described, we endeavor to explain and better understand the evolution of the organizational transformation and the paths that such changes are likely to open, by attempting to provide answers to the following questions:

1. How have engineering companies really changed in the last generation?

2. What were the driving forces of this transformation?

3. What future trajectories are possible for the creation of a viable model for AEC firms?

To answer these three questions, we have:

1. Set the starting or benchmark point by referring to the context of the AEC industry from the 1990 to the early 2000 both in terms of the economy and industry growth. By doing so, we set the benchmark against which future changes might have occurred after 2010 on three fronts: the organizational firm, its managerial structure and its procurement process.

2. Described the vision of the AEC, civil engineering and infrastructure scenery 20 to 25 years hence, according to the research literature assumptions and projections made between 1990 and 2005;

3. Identified major catalytic sources through a dual approach: a) A micro qualitative review of leading papers on various changes in the AEC/civil

engineering/construction landscape from 2005 to 2016; b) a high level quantitative review on how key-word driven research trends emerged over the 1966-2015 period on 'Risk', 'Finance' and 'Market Risk'.

4. Circumscribed the most critical areas of change for the period between 1990-2005 for research assumptions and emerging changes post 2010. This stems both from the review of literature and a dozen semi-structured interviews with executives of engineering firms from Montreal and Calgary.

5. Verified the asymmetries between major research assumptions and key-word evolution over time and the actual industry trends now shaping the AEC industry in 2015, by referring to research on productivity.

6. Carried a survey on risk perception amongst infrastructure professionals attending the 2017 10th Global infrastructure leadership forum staged in Montreal.

Our findings reveal that major changes occurred on three fronts. First, construction engineering is becoming a soft industry, leaving the hard building work to a world of ongoing small to medium-size firms (*SME*) and craftsmen teams increasingly specialized in the mobilization and management local project procurement. Second, the split of the industry between soft horizontal (*SH*) straight-through project servicing and hard vertical (*HV*) work has helped to mature how risk is being managed (*Wolstenholme, 2010 ; Robinson et al. 2016)*. Third, new means of decision-making have emerged among large to multinational firms in selecting and managing their projects thanks to a wide range of new technology and intelligence systems.

All in all, AEC firms may have altered their organic form and processes, but little evidence reveals structural changes, as productivity figures don't seem to have improved significantly since the 1990s around the world, with perhaps the exceptions of the UK, Australia and developing countries (*OECD, 2018; Wolstenholme, 2010*).

The major causes of those three changes are six major pressure points acting as catalysts: technology, finance, environment, market, regulators and human resources with a direct effect on the dynamics of the AEC system and the way risks are being managed and decisions made.

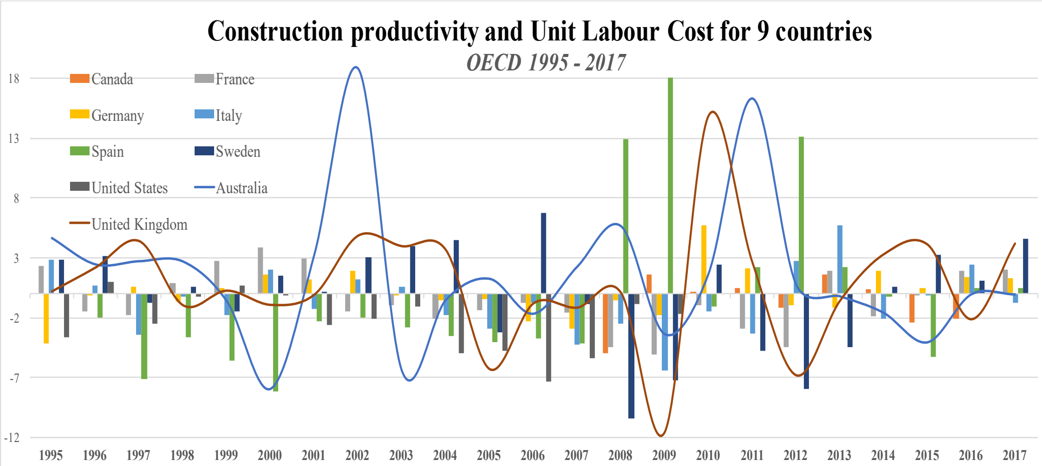


Figure 2: Aside from the United Kingdom and Australia, where net gains were positive although meagre, most other countries show stagnant to negative growth if construction productivity. As Table 4 will show later, the fact that construction/infrastructure gained so much weight in GDP terms is mainly due to growth in size, the retrenchment of the manufacturing industry in most developed countries as a result of massive outsourcing to emerging countries and the steep rise of

The research begins with a review of literature *('white' for academic and 'grey' for professional*) covering those topics with the following approach:

Outlining the most recent transformation of the industry prior to the new millennium of 2000;

a) Focusing on the market and economic scenery over the period of 1990 through 2017 that propelled the AEC
b) Looking at studies projecting future outcomes of the industry
c) Concentrating on more specific and micro-oriented research, with a strong emphasis on post 2010 articles, on the various issues and pressure points, which have long characterized the industry or sprung since the late 1990s.

The second section outlines the market and economic scenery over the period of 1990 through 2017. The third illustrates the waves of changes that triggered major transformations by concentrating on more specific and micro-oriented research, with a strong emphasis on post-2010 articles describing each of these pressure points in more details. The fourth section outlines a risk perception survey conducted in March 2017 among 90 attendees of a Global Infrastructure Leadership Forum.

The fifth section outlines the search for the emerging AEC model through new shapes of risk management and decision-making. The last section concludes by discussing key weaknesses of this research and opening new vistas for future investigation.

I- LITERATURE REVIEW, RESEARCH DATA AND METHODOLOGY*

The literature review was divided in three parts:

Leaving aside the Katsanis and Davidson's H2020 series, the first task was to search for papers that included in their titles the words 'Future', 'Vision' and 'Horizon' in order to capture a wide spectrum of expectations about the AEC industry up to 2020 for a total of 16 papers, including Harty 2007 who reviewed 13 papers (*of which 8 are from the UK*) between 1998 and 2005 and covered a range of issues liable to affect construction in the future. Harty (2007) extracted six major themes: technological, environmental, human, economic, governance and other (*essentially wild cards and major shocks*). Oddly enough, he mentions risk only twice: once to suggest that standardized components could reduce risk and a second time to underline the hazard of integrated supply chains and AEC functions (*AEC*). Such integration does not account for the "conflicting interests and expectations of construction firms and practitioners, and the risks of introducing dependency and exposing core competencies that interorganizational collaboration can produce". "In reality, Harty adds, integrating supply chains, especially in a consistent way and across a number of

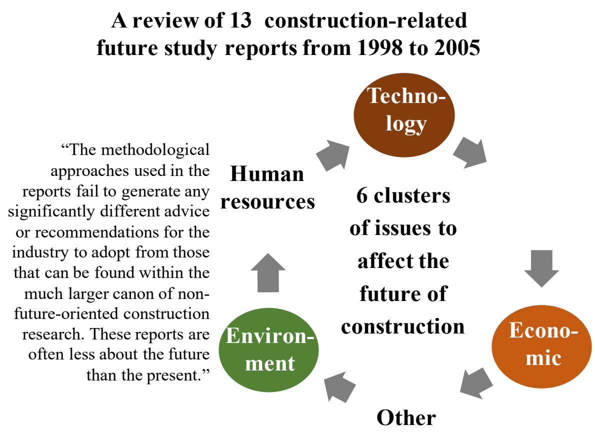


Figure 3: Three (*technology, environment and human resources*) of Harty, 2007 key issues are shared with our six sources of pressures points. Other points partly or entirely missing are market factors, corporate finance and regulation

separate projects, is a hugely difficult challenge requiring a significant change in both the practices of the whole sector, and the assumptions and expectations of its constituents (*c.f. Dainty et al. , 2001*)."

1. There is not a single mention of finance and no direct reference to decision-making, either in terms of corporate strategy or concern.

Ten years later, Harty (2017) expanded on construction management research by making only three references to risk and none to finance. Other papers using

* Methodological notes are available in the Apendix.

'Future', 'Vision' or 'Horizon' in their titles rarely refer to risk or finance, as the Table 1 shows:

Table 1: Omission of risk and finance in the future/vision/horizon articles on the AEC		
Research articles	**Times used the word of 'Risk'**	**Times used the word of 'Finance'**
1. Pennoni, 1992	1	0
2. Katsanis, 1995	3	1
3. Bon, 1997	0	0
4. Katsanis, 1996	2	0
5. Katsanis, 1998	3	0
6. Bourdeau, 1999	3	2
7. Katsanis, 1999	0	0
8. Voros, 2012	1	1
9. Katsanis, 2001	1	1
10. CRCCI, 2004	14	2
11. Chan et al., 2005	3	0
12. Soetanto et al., 2006 *(reviews 13 reports from 1998 through 2005)*	0	0
13. Harty, 2007 (*reviews 12 other articles and reports out of 13*)	2	0
14. Davidson, 2009	2	0
15. Borg & Lindt, 2010	14	2
16. Harty, 2017	3	0

Some exceptions are Lindt and Borg (2010) and CRCCI (2004), though they do not directly reference risk management or market risk for an AEC firm, aside from saying that greater risk should generate greater profit or that risk should be equally shared among project stakeholders. On the other hand, Chan et al. (2005) are the only ones to mention risk management three times by referring to three different reports on the future of construction[IV].

This "Future"-oriented literature review shows that AEC organizations, and especially those that rose to the level of nationals and multinationals have grown more complex and diversified with greater changes occurring internally than externally. The changes are as follow:

a) A swift rise of risk management awareness, beyond technical and logistic factors, took shape on the eve of the new millennium. However, the review of literature about the future of AEC between 1990 and 2010 reveals that risk management is virtually absent from most articles, despite the birth of 'soft systems' in the late 1980s (*Edwards, 1998*).

[IV] The three reports are: *"**The future of the design and construction industry (projection to 2015)**"* from the Civil Engineering Research Foundation – CERF, 2000; *"**Vision 2020**"* from the Construction Industry Institute-CII of the University of Texas, 1999; "***The professionals' choice – the future of the built environment professionals***" from the Commission for Architecture and the Built Environment-CABE, 2003.

b) The new role of finance was omitted from the whole future AEC scenery, not only in terms of performance, but as a key engine on the eve of the most formidable consolidation drive in the history of the AEC industry.

c) An increasingly service-driven industry as opposed to a product one, with all the means required to ensure the appropriate transition. That is where most of the change of culture is happening.

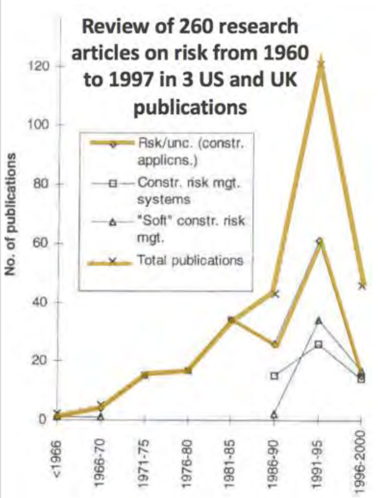


Figure 4: Researchers' main concern about risk between 1960 and 1995 applied to quant theories and techniques of construction progress (*Edwards, 1998*). In the early 1970s, systems theory becomes a popular vehicle to develop risk management. The adoption of a systems approach to construction risk management occurs around 1985. "Finally, a 'soft systems' approach to risk management appears in the late 1980s and accelerates rapidly in response to the development of 'soft systems' theory (*Checkland & Scholes 1990*)."

The second task what to verify how the literature evolved over the issues of risk and finance from 1966 through 2017, as shown in table 2. This was done by using two sets of key words: variable ones, such as construction, civil engineering (*CE*) and infrastructure (*infra*), and independent ones, such as 'Risk' and 'Finance' as follows:

Table 2: Applying keywords to 'Risk' and 'Finance' through Google Scholar and ACE library

Combinations linked to the independent keyword of 'Risk'	Combinations linked to the independent keyword of 'Finance'
Construction	Construction
Infrastructure	Infrastructure
Civil engineering (CE)	Civil engineering (CE)
CE and construction	CE and construction

The search covers the period spanning over 50 years with periodizations (*or divisions*) of 5 years apart (*pursuing the model of Edwards, 1998*). In order to avoid various biases of knowledge bases (*KB*), as further explained in the discussion section, two universes were used: Google Scholar (*GS*), the world's largest knowledge base, and the American Society of Civil Engineers' (ASCE) Library. The main advantage of such combination is to rely on a much larger generic KB (*through GS*) to verify if the trends it reveals are confirmed in the more focused world (*ranging from 12 times up to nearly 200 times*) of ASCE as Table 3 shows. The second reason is that the ASCE KB contains a relatively higher rate of contribution from practitioners. This data analysis approach enabled us to identity trends in awareness (*measured by size*) and awakening (*illustrated by breakout jumps*), verify dispersion rate of ideas between generalists (*Google Scholar*) and specialists (*ASCE*) and capture the variance of research between the three variable key words according to their breakout years. The awareness or size effect is aimed at measuring the academic reflection of the industry's main concerns

Table 3: **Gaps and Trends between Knowledge bases of Google Scholar and ASCE**

Comparing the size of two knowledge database on the keyword combination of 'Risk'				
Dependent key-word	Construction	Infrastructure	Civil Engineering (CE)	CE & Construction
Total Google Scholar (GS) in '000	4622,4	1916,17	616,37	274,03
Total ASCE in units	23747	11450	20096	15373
Multiple = (GS*1000)/ASCE:	**194,65**	**167,35**	**30,67**	**17,83**
Comparing the size of two knowledge database on the keyword combination of 'Finance'				
Total Google Scholar (GS) in '000	1968,9	1100,9	301,52	144,54
Total ASCE in units	17017	7860	13570	11621
Multiple = (GS*1000)/ASCE:	**115,70**	**140,06**	**22,22**	**12,44**
Data were tabulated from Google Scholar and ASCE Library on May 2nd 2018				
Comparing the size of two knowledge database on the keyword combination of 'Market Risk'				
Dependent key-word	Construction	Construction & Infrastructure	Civil Engineering (CE)	CE & Construction
Total Google Scholar (GS) in '000	1882,66	340,47	195,486	132,43
Total ASCE in units	4971	2370	73	64
Multiple = (GS*1000)/ASCE:	**378,73**	**143,66**	**2677,89**	**2069,22**

Comparing the size of research posted respectively by the two knowledge databases (*KB*) reveals wide gaps between the three independent keywords of 'Risk', 'Finance' and 'Market Risk'. The Google Scholar (GS) KB size ranges between 70 (*under 'Finance'*), 105 (under 'Risk') and up to 341 times larger (*under 'Market Risk'*) that of the ASCE Library. Two reasons may explain such differences. GS is far more generic and covers a much wider sphere of risks than the ASCE KB. On the other hand, most practitioners contributing to ASCE are presumably much closer to CE operations and management than to financial operations and especially market risk considerations.

while the awakening effect (*from a breakout year*), illustrated by a steeper curve, tends to express the retroactivity of research to industry practices thanks to more applied research based on empirical results.

From this search, four major differences appear.

- The ASCE KB appears as a trendsetter by introducing research involving the keywords of Risk and Finance in 1981-1985, 5 to 20 years before the GS KB. However, the GS KB was much quicker to recognized the keyword of "Market Risk', a critical factor in the major industry consolidation that occurred during 1990s through to 2015.
- The steepness (or *CAGR slope*) of the awakening curve is also much higher under the ASCE KB, with the exception of two combinations with 'Finance': Construction and CE. The compounded average growth rate (*CAGR*) aims to measure the real build-up or take-off of research in each KB. The CAGR is calculated to cover a period starting only with a growth disruption or break-out growth in number of articles of around 100% or more from one year to another (*see appendices for further description*), instead of with the beginning of column series in 1966. The CAGR measures the strength and persistence of the influence it may have retroactively on the industry.

- Third, the dispersion between keyword variables, measured by comparing the standard deviation of volume of research under each combination, is four times greater under the GS KB than under that of ASCE *(≈ 100% versus ≈ 25%)*, except for 'Market Risk' where the dispersion rate is only slightly higher (*140% vs 121%*). This is a reflection of the higher noise level of GS.

If those jumps were not taken into account to estimate the CAGR, the growth rate tabulation would be too linear and would hide the real break-out/takeoff events. Because of the high specialty of ASCE KB, there is little if any variance in the disruptive growth year. By variance, we mean here the variation of break-out years between different pairs. For instance, all four keyword combinations share the same break-out (*1981-1985*) for both 'Risk' and 'Finance', with the sole exception of the CE-Construction-Risk combination emerging 5 years earlier.

As a significant research key-word, '**risk**' appeared fairly late in the AEC industry literature. Sampling Google Scholar *(=GS)*, '**risk**' only takes off in pair with construction after 1986 in academic and professional papers, followed by cascades of

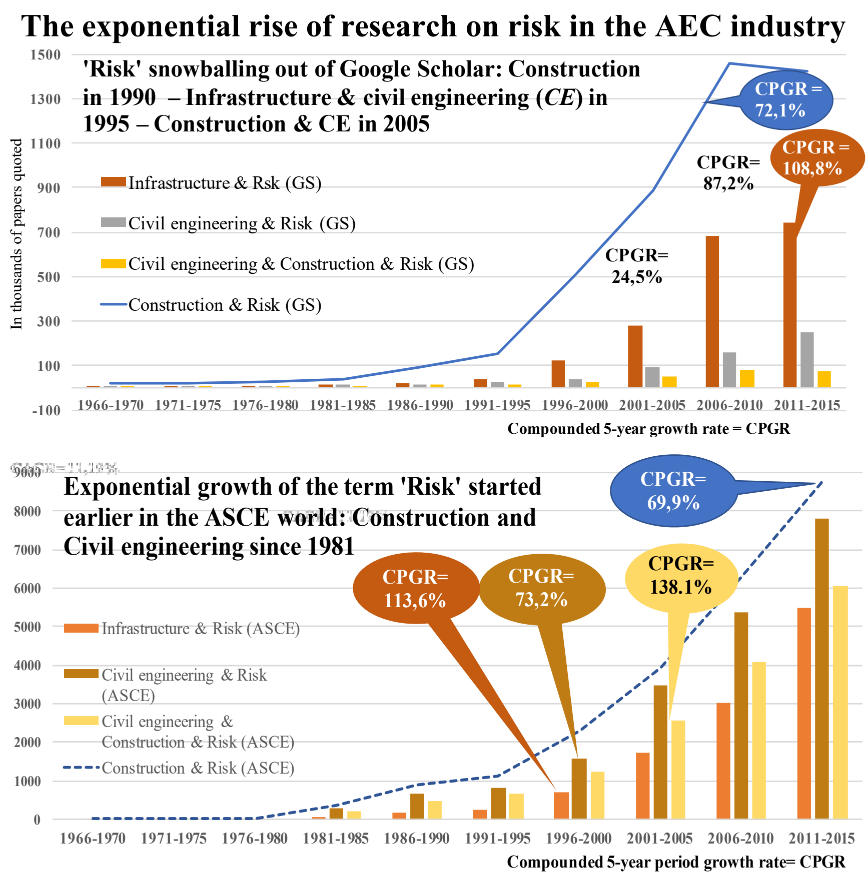


Figure 5: Tabulation of research in Google Scholar shows a later exponential growth for the term 'risk' in the world of Architecture, Engineering and Construction (*AEC*). The greatest acceleration however belongs to the pair of key words 'Infrastructure & Risk' in the ASCE world with a compound rate nearly twice as fast as the pair of Construction & Risk in. (*tabulated from GS and ASCE library on May 2nd, 2018*)

5 years for infrastructure (1991-1995), civil engineering (CE) (*1996-2000*) and CE & Construction (*2001-05*), as the applications of risk expand. Yet, research grows the quickest in 'Infrastructure' ('infra'), followed by CE. This corresponds with the emerging logic of 'risk sharing' between stakeholders stemming from the birth of the PPP/PFI. '**Risk**' emerged about 5 years earlier in the much smaller world of the American Society of Civil Engineers (*ASCE*), with 100 times less references. More focused than Google Scholar because of a relatively higher contribution from practitioners, the momentum between all four headings with risk (*construction,*

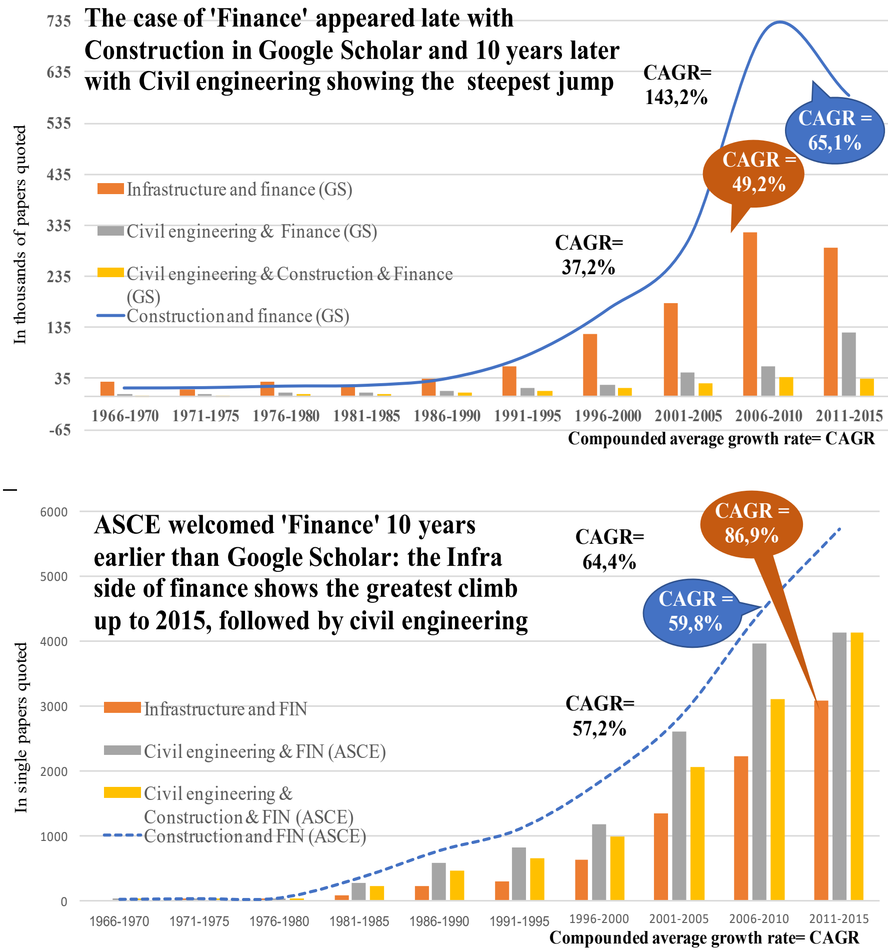


Figure 6: The two illustrations compare the result of a key-word-driven search of academic and professional papers combining four major headings (*Construction, Infra***,** *CE and CE& construction***)** with finance in Google Scholar and the ASCE library.

infrastructure, CE and the three together) moves far more in tandem with much steeper awakening in infra (*CAGR nearly double the construction pair*) than for Google.
Yet, unlike the Google Scholar census where it comes last in both awareness (*general recognition and knowledge*) and awakening (*discernment and realization*), the trio of CE-Construction- Risk topples the pair of Infra-Risk in volume and records the fastest catch-up of all for combinations due to its earlier start.

Although construction still generates the largest literature around '**finance**', the pair of CE-Finance appears as a very late starter *(post 2001*) under the KB of GS but records a sharp awakening (*CAGR=143,2%*) over the last ten years of the series. This corresponds clearly with the real take-off of the PPP/PFI in Australia, Europe and Canada in the mid-1990s. By contrast, it is the pair of Infra-Finance that topples the other in terms of research growth under the ASCE KB.

Not surprisingly, the keyword of 'Market Risk' appears strongest with the quickest research awakening under the GS KB, although Google shows a much higher variance between the four combinations with the trio of Construction-Infra-MR breaking out first in the late 1970s, followed by CE and, 10 years later, by Construction and the trio of CE-Construction-MR. This time, Google appears to be the trend-setter, with the ASCE trailiing behind in the late 1980s through the early 2000s for the trio CE-Construction-MR and the combo of CE-MR.

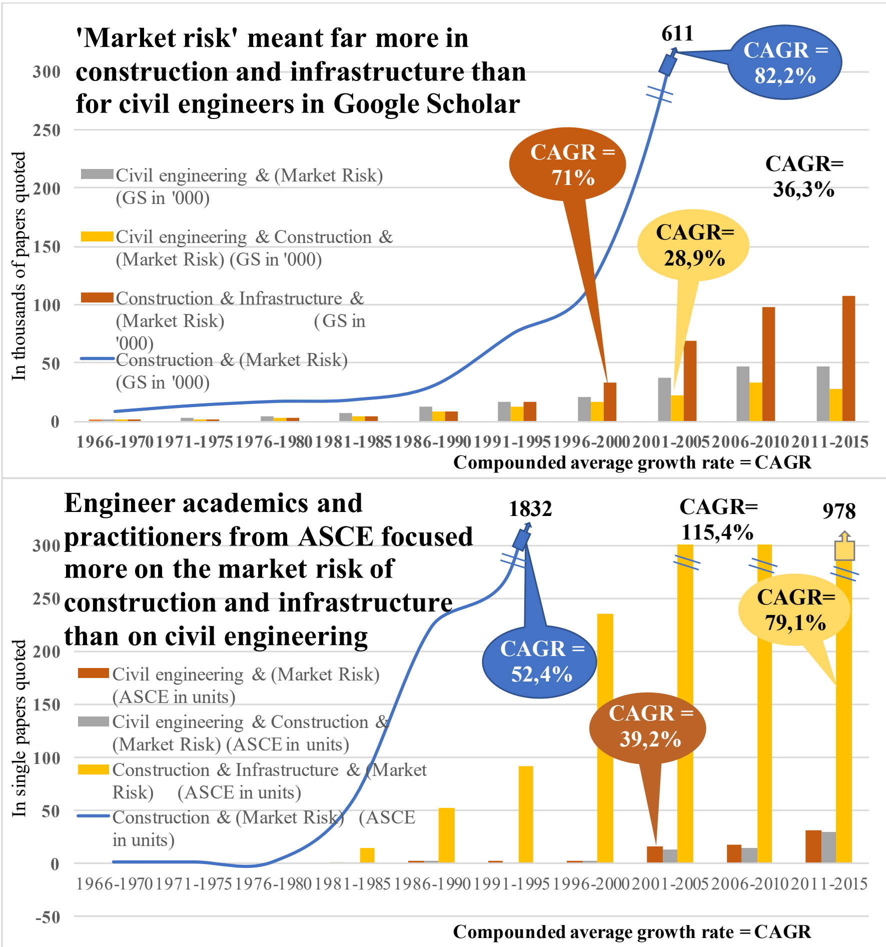


Figure 7: A huge size gap appears in both knowledge databases (*KB*) between the combo of Construction and 'Market Risk' and the three others. Even the ASCE KB can not maintain the same low dispersion rate (*standard deviation*) as with the other Risk and Finance combos. Under both KB, the notion of 'Market risk' is marginally recognized by civil engineering (*CE*).

2. The third task was to identify emerging new practices that might connect or spring from the six major sources of pressure points. Such a search was driven by various keywords liable to define, expand the use of, explore the opportunities or reveal the constraints that might trigger various applications or derivatives of pressure points. Over 124 papers were found that could elaborate on the various dimensions of strictly exogenous factors. A particular focus was put on the search for papers after 2010. The first reason was to distance those researches from the Future articles on AEC to avoid wide overlaps. The second was to detect two major behavioral derivatives of those pressure points: the decision-making process and the risk management, two endogenous components of the change process of AEC firms.

In light of the H2020 series and the review of literature, here is how each of these six reciprocal forces pressured the industry for a change that is only now emerging:

a) Mergers and acquisitions, as well as various alliance forms (*Sparkling et al., 2017; Sznewais, 2017; Livingston, 2010; McIntyre, 2018; Morris, 2015; Shen, 2017; Sanderson, 2017*) are accelerating to meet growing competition (*Bhattacharya et al. 2009; Kreitl, 2002; Kenney, 2008; Shuster, 2011*).
b) Emerging Public-Private partnership and privatization of infrastructures (*Liu, 2016; Lam, 2015; Hall, 2010; Jayasuriya, 2016; Hueskes, 2017; Marty, 2013*) have triggered a major catch-up effect on Grand Public Interest Projects (*GPIP*) by governments around the world.
c) The rise of new finance (*Saha et al., 2018; Diaz, 2017; Zawawi,2014; Gray, 2015; Gemson, 2015, Esty, 2004; Smyth, 2017; Whitfield 2016; Whitfield 2017*) has altered the way capital is allocated to the industry and the Modigliani & Miller (*1958*) view that corporate finance decisions (*between debt and equity*) do not affect firm value.

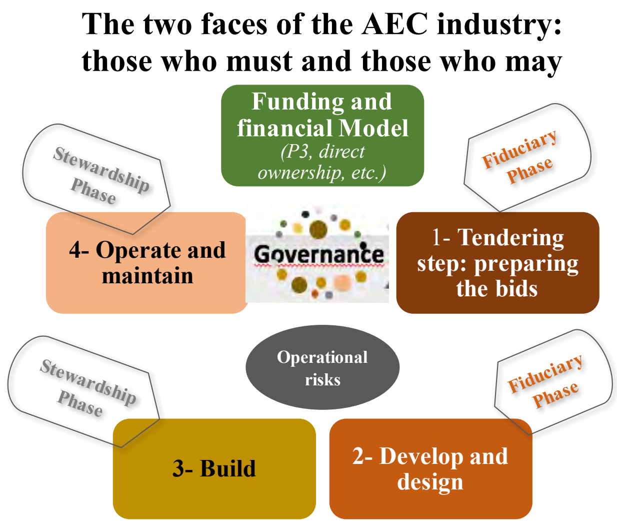


Figure 8 – This illustration shows the two dimensions of obligations between design professionals, acting as consultants (≈ *fiduciaries*) with significant managerial discretion and an obligation of means, and building contractors, acting as stewards with limited managerial discretion and an obligation of results.

d) Rising pressure for improved environmental concern and sustainability (*Olanipekun, 2117; Rao et al. 2015; Hojem, 2011; Koch, 2013; Siew, 2016; Rodriguez-Nikl, 2015; Martinez, 2015; Kajander, 2016*, *Zavadskas et al., 2016; Yeheyis, 2013*) are combined to introduce brand new practices and risk controls over various procurement stages.
e) The extension of Design-Built to Finance, Operate and Maintain (*FDBOM*) (*Braun Deshaies, 2012 ; Mogalli, 2016; Berns, 2009; Siew, 2116*) and the integration of fiduciary and credit risks (*Kong et al., 2008; Camilleri & Clarke, 2011; Castro, 2011; Edwards, 2012; Erger, 2012; Gurney, 2014, Kapliński, 2008; Schwarz, 2007*) have expanded the capacity and competitiveness of engineering & construction firms globally, while raising the bar of litigations and transactional cost.
f) The impact of technology and digitization (*Agarwal, 2016; Bansal, 2012; Bilal et al., 2016; de Laubier, 2018; Rao, 2015;*) against growing constraints of skilled labor gaps and a shortage of engineers (*Fiori, 2003; Green, 2009; Unesco, 2012*; *Ellis, 2017*) has flattened the classic hierarchy of many organizations;
g) The regulatory burden continued to grow by imposing new constraints on the industry's behavior (*Abdallah, 2007*, *Anslow, 2015*, *Bastianelli III, 2008; Zhong, 2012; Beach, 2015; Schwartz, 2017; Matsuura, 2017, Umeokafor, 2014, EU, 2015, Marques, 2017, Diaz, 2017, Ryan 2012, Nea, 2005, Tao, 2014, Testa, 2011*).

II-PUTTING THINGS INTO CONTEXT

A series of articles under the general rubric "*Horizon 2020*" undertook to forecast the future of directions on the building industry in North America in the 1990's. The focus of these articles were several key areas such as procurements practices, the diffusion of technological developments, the changing organizational structures as well as influences exerted on these themes from the broader socioeconomic environment. The connecting thread amongst these articles was a systems dynamics approach that examined the interdependencies of these areas based of critical paradigms that prevailed at that time.

In this paper (*with the benefit of hindsight*), the influence that these paradigms on the trajectory of various elements that have shaped the AEC industry over the last twenty years is examined. The AEC industry is viewed as a complex dynamic system subject to prevailing forces that are likely to shape how AEC organizations evolve and transform over the next twenty years.

In this process, the reciprocal influences that technology, various stakeholders, society and government exert on one another and how these influences shape the reorganization of firms, projects, inter-relationships and contractual arrangements (*including offshoring*), business models and practices are considered.
The emphasis is placed on the firm's operations and the role they play on the procurement of engineering groups to infrastructure projects.

Two major cycles marked the growth of the AEC industry over 50 years through to 2017 and shaped significantly its business model under historically high financial and economic pressure, both upwards in the late 1990s and mid 2000s, and downwards, following 2000 and after the Great Financial Crisis (*GFC*) of 2008

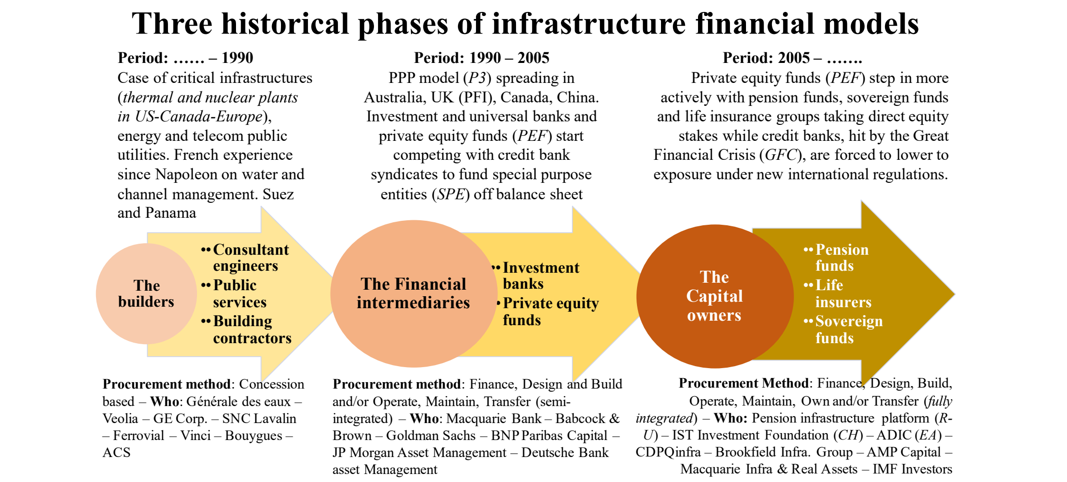


Figure 9 – Three financial crises occurred during the last two phases, with the first one in 1997, hitting Asia and Russia, the second was the technology bubble of 2000 and the third was the Great Financial Crisis of 2008. Over that period, credit banks saw their role shrink under the pressure of heavy handed central banks to the benefit of the investment industry.

Stagflation and contraction: From 1964 through 1995, when leading forecast studies started in the construction industry, the growth was purely illusory. At the end of 1995 according to the US Census, the annual value of construction put in place and seasonally adjusted reached $568 billion or roughly 7-times the value recorded when the first US census was held in 1964. However, such spectacular growth had been puffed up by years of double digit inflation in the late 60s and 70s. As a result, once converted into constant dollars, this explosive growth uncovered serious stagflation. Growth proved to be 5 times slower than what appeared in balance sheets, while return on investment narrowed significantly. The profit squeeze *in the early 90s* gave way to various business processes of reengineerings (*or BPR*) (*redesign of core business processes to achieve radical improvements in productivity, cycle times and quality*) such as Total Quality Management-TQM through the emergence of ISO 9000, partnering and value engineering (*to ensure that required functions are performed at the lowest possible overall cost*). Contractual arrangements (*cases of Jacobs Engineering, Bechtel Group, Fluor Corporation and Washington Group International*) were also reviewed intensely to improve value for shareholders and counter increasing market risks of complex projects and stiffer competition. Economies of scope and scale were gained with the launch of the 5th largest merger and acquisition wave (*cases of SNC-Lavalin, AECOM, Stantec, WSP, Jacobs Engineering, KBR*), while de-consolidation of conglomerate approaches (*case of Fluor Corp.*) was undertaken to improve business focus and net margins. The contracting revenue of the top 250 international contractors reached US$1430.8 billion in 2014, of which more than one third was derived from overseas.

Table 4: The Des-industrialization of 5 key economies and the rise of AEC

Share of value added	Germany	France	Japan	Sweden	United States
Manufacturing in 2015	4,94	5,53	5,56	6,26	4,19
Construction. In 2015	23,06	11,53	20,90	15,45	12,27
Professional, scientific, support services -**PSSS** in 2015	12,91	10,996	7,271	11,197	11,846
Manufacturing (1980-2015)	-22,4%	-53,3%	-25,9%	-36,9%	-48,2%
Construction. (1980-2015)	-33,2%	-28,2%	-40,9%	-2,2%	-17,8%
Contruction+25% of PSSS -1995-2015	-20,3%	2,6%	-25,0%	20,6%	1,4%
Share of employment	**Germany**	**France**	**Japan**	**Sweden**	**United States**
Construction	-24%	-34,8%	-23,2%	-9,1%	8,6%
Manufacturing	-7,2%	-52,4%	-33,0%	-0,60	-0,50

Table 4: The declining share of value added and of employment in both manufacturing and construction since 1980 across five different types of economic models (*Anglo-saxon, Rhineland, Scandinavian, Latin and Nippon*) is probably the strongest symptom of the des-industrialization phenomenon of developed economies. Yet, when design services are added to statistics, as they account for about 25% of the Professional, scientific and support services of national accounts (*PSSS*), the fall of construction dwindles and even reverses in France, Sweden and in the USA. The rise of engineering and architectural services has not only slowed the value erosion of construction, in addition to diversifying market risk but contributes to its modernization, as we shall see in part three. This will have a catalytic effect to stimulate servitization (=*facilities or real asset management*) explains the attraction of institutional money.

Acceleration and global expansion: As overall inflation trickled down (*except for building materials under the pressure of soaring emerging markets*), building activities accelerated. From 1996 onwards and despite the TMT crash of 2001 and the Great Recession of 2008, annual value of US construction put in place and seasonally adjusted more than doubled to exceed $1.2 trillion on the eve of 2017. The same phenomenon occurred in Canada (*8-fold growth over 1964-1995 in current dollars*) with, however, a much higher rate of acceleration through 2016 (*3.2 times in current CDA dollars vs 2 times in current US dollars*) to reach $86 billion, as a result of the world commodities' boom in energy, mining and forestry.

Profitability recovered thanks to unprecedented industry consolidation and stronger management controls by financial players such hedge funds and private equity firms, both liaising with their major funders: pension funds that were desperate to improve their return on capital, in light of historically low interest rates, to meet their annuity obligations. The new millennium marked a spell in public listings of construction and engineering firms such as Chicago Bridge, KBR, AECOM, WSP (*the latter through a back-door listing in London*), with a majority of shareholders (*over 80%*) coming from the institutional fields (*fund managers, pension funds and mutual funds*).

This tremendous push from finance and the snowballing growth of P3 projects around the world opened the door to increasing AEC integration with the emergence of service-led construction, which extended the Design-Build approach to Maintenance and Operate.

The original forecast of innovation through new IT facilities (*the World Wide Web only appeared in the mid-1990s*) underestimated the trend that paved the way to lean construction, building information modeling (*BIM*), Big data management and virtual design and construction (*VDC*).

III- WAVES OF CHANGE

The **Real Asset Market** case involved three dynamic components:

First, the wave of **globalization** following a series of bilateral and multilateral free trade agreements triggered by the birth of the European Union and the Euro currency by the turn of the millennium (*Wong et al. 2010*). The three major financial crises of 1997, 2000 and 2008 incentivized AEC firms to seek greater opportunities abroad. The

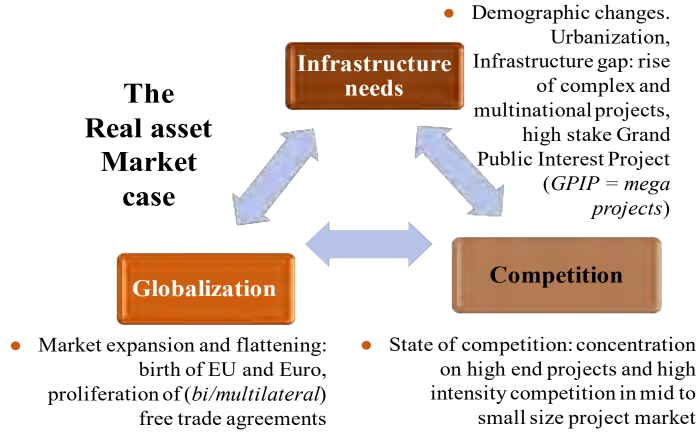


Figure 10 – The rise of emerging market competitors and three financial crises: The explosion of commodity prices and the rise of new players from Europe and emerging markets (*India, China, Brazil, Turkey, Mexico, etc.*), the latter due to experience gained by local promoters until 2012, accelerated competition in Western countries while the need to restore (*in developed countries*) and build (*in developing countries*) infrastructures increased the urge to consolidate globally.

international design firms (*IDF - mainly engineering consulting firms*) saw their revenue triple from 2003 to 2011 and reach nearly $58 billion (*Jiang et al. 2016*). Design firms from Europe, America, Canada, Australia, Japan, China, and Korea control 95% of international market share. Yet, the market remains fairly competitive, with high concentration levels registered mainly among high density sectors (*manufacturing, hazardous waste and telecom all sharing a concentration rate in excess of 50% among 4 leader IDFs*). The case of 10 mega infrastructure projects by the Hong Kong Authorities in 2008 shows that joint venture partnering can lower market concentration for smaller and active contractors.

For occasional (*and larger size*) contractors however, forming JVs increases market concentration. Kreitl (*2002*) shows that joint ventures (*JV*) accounted for only a fraction of consulting engineers' growth over the 1990-1998 period, unlike what the Rolodex approach in *Horizon 2020* series had projected, except for small and partnership firms that used JV (*yet for only 4% to 13%*) as an easier step towards virtual consolidation around a single project. The reluctance to use JVs or an alliance mode, according to Kreitl (*2002*), was due to the higher risk perception of JVs by survey respondents. Nonetheless, Ingram (*2016*) notes a "growing use of joint ventures and alliances to deliver projects", a fact that many major consulting firms (*BCG, McKinsey, Bain*

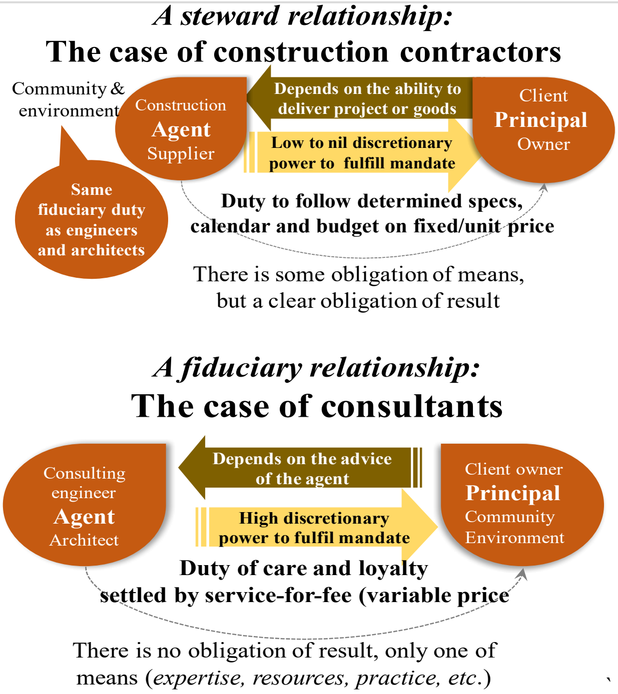


Figure 11 – The contractor is a steward that must abide by the instructions of design and technical specifications. However, what happens if the same contractor is also in charge of the design? Does his obligation of results melt or mix up with the consulting firm's obligation of means? The potential for conflicts of interest is heightened in what is called an 'incomplete contract' (*Zingalez, 2017*) or 'fuzzy arrangements' for clients, as suggested by Sacconi (*2003*), by which a wide range of contingencies simply can not all be included in a contract. Katsanis (*1998*), had already highlighted two key issues: 1- The requirement of a high degree of sophistication from the owner to deal with the complexity of drawing up contracts, a task traditionally delegated to the design professional; 2- The challenging of converting the owner's needs into adequate contracting languages. "The owner has recourse to independent advice from the design professional on matters of need, functional performance and/or prescriptive specifications (*PS*). The execution of these specifications becomes the responsibility of the builder. If a problem arises, the decision must first be made as to who is responsible…"

Capital) confirms today. It remains difficult to say which of the construction or engineering firms are taking the lead in the M&A play. Shuster (2011) outlines the fact that FMI corporation, acting as a merchant bank in the AEC field, recorded in 2010 alone that construction firms took over engineering firms in 11 percent of the M&A cases, whereas 9% involved engineering firms taking over construction firms. Market risk was the main driver, recalled a director of FMI Corp. Michael Landry: "If you lose money in one section, you can make it up in another activity" (*Shuster, 2011*).

The supply side of countries eager to restore or build their infrastructures intensified this competition and fueled a significant rise of commodity prices worldwide. While the infrastructure market dropped significantly after the 2008 financial crisis, the momentum persisted across developing countries until 2012.

Second, the case of **Corporate and Project finance** is the most critical pressure point that helped most transform the AEC industry.

Consolidation – The combination of regulatory and commercial pressures in a rather low economic cycle of public expenditure triggered a major consolidation wave worldwide with little organic gains overall *(Lu, 2014; Choi 2004; PwC 2015; Bleßmann 2012)*. Three major waves of mergers and acquisitions (*M&A*) marked the period of the 80s, at the start of the new millennium and after 2010. From 1995 through 2017, some 33,208 AEC companies changed hands around the world, mainly in industrial countries, with a cumulative value of $758 billion. Over 2000 companies changed hands since 2010 (*Mullen, 2016*) for well over $400 billion. Of the total, civil engineering leads the pack and 40% of mergers and acquisitions (*M&A*) were powered by private equity institutional investors instead of more obvious strategic partners from the industry. Whereas North America remains the largest market in absolute size, annual compounds growth of global M&A was the highest in Asia-Pacific (*annual compound rate of 27% vs 13% in Europe and 10% in N. America*). In Europe, most of the growth happened during the 1990s amongst the top 100 design firms where staff increased by 120% and turnover *(=sales*) by 170% (*Kreitl, 2002*), with listed companies *(=PLCs*) showing the greatest increase (*average of ≈ 250% in staff and ≈ 270% in sales*). No wonder that nearly half (≈ 49%) of PLCs' growth was attributed to M&A. Short of securities that could be used partly as means of payment for an acquisition, smaller unlisted companies and partnerships relied on M&A for only 10% to 28% of their expansion.

Unlike other manufacturers, where process and systems overtake cultural and ethnic factors, the degree of multiculturalism (*cultural aspects and personal issues*) of a target company is far more attractive to a service firm, such as architectural and engineering firms, than to a manufacturing one (*Kreitl, 2002; Pablo, 1994; Pablo, 2004; Greenwood, 1994)* because of the much higher contribution of people than systems to sales and profits.
On the contracting *(=stewardship*) side, M&A were much less popular for four reasons. First, because they

brought little change (*19% according to a survey of 1000 IT executives by Ingram, 2016*), except in France (*41%*). Second, because multiculturalism is already present but has no effect on the business development side. Third, because contractors are 'job companies' with little medium to long term financial rent, unlike design professionals (*Leiringer, 2010*). Fourth, because they represent the greatest source of systematic risks within the Architecture-Engineering-Construction (*AEC*) triangle for any investor.

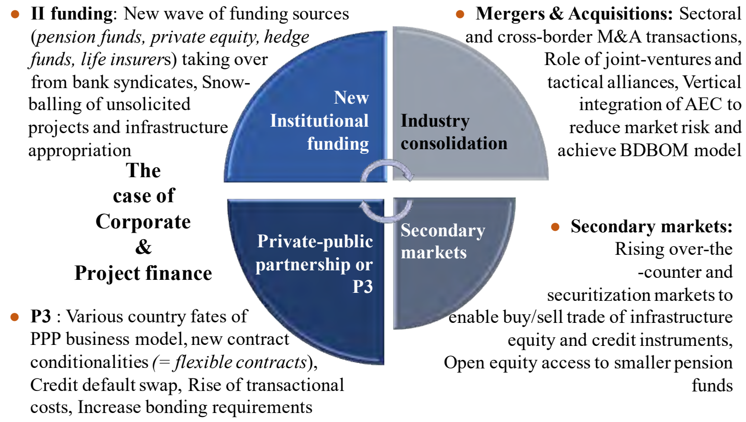


Figure 12 – **Reaction to markets**: The case of corporate and project finance probably shows the most critical pressure point that changed the real face of the industry, by ensuring its structural integration and raising further transaction costs beyond the range of 5% to 10% of a large project.

The case of three North-American engineering groups is a good illustration of the consolidation wave that propelled so many firms. Most of those M&A waves, especially the second and third waves, were funded by large institutional investors that merely accompanied their investee firms by matching their equity share for each new acquisition. These consolidations became the major stepping stone for international groups to expand their services and move into a fully integrated supply model of Finance, Design, Build, Operate and Maintain (*FDBOM or what is called DBOO, the last O for own*), without – in a growing number of cases – any option to transfer an infrastructure to the public authorities.

Engineering firms World rank *ENR-2016*	**Turnover in USD billion**		**Net profits in USD millions** *Multiple*Multiple	
Fluor Corp. **- 15th** as contractor	1995:9,3	2015: 18,1	1995: 232	2015: 475 = **6**
WSP(*ex-Genivar*) **- 1st** as designer	1995:0,13	2015: 4,5	1995: 17,4	2015: 441 = **25**
SNC Lavalin **- 41th** as contractor	1995:1,03	2015: 9,6	1995: 31,3	2015: 404 = **13**

Table 5: Sources : annual reports, Bloomberg, « *M&A International Inc. Infrastructure Construction M&A : Opportunities in Adversity* », M&A International, August 2010, « *US Engineering & Construction Sector (E&C)* », Steven M. Fisher, UBS, August 2011

Institutional investors' funding – Aside from investing heavily in the AEC industry, pension funds, life insurers, sovereign funds and university endowment funds started to invest into infrastructure projects, either through private equity funds (*PEF*) or directly through a growing number of unsolicited projects (*Hodges and Dellacha, 2007*), including Grand Public Interest (*and often complex*) Projects (*GPIP*). Across developing economies, up to 23% of PPP projects were unsolicited, "which raises some concerns about transparency in project selection. Lack of competition in contract award, in the form of direct negotiations, is also prevalent in the energy sector (*33%*) and among projects in low-income countries (*39%*)" (*World Bank, 2016b*).

The rise of this new finance is a sort of a relay, inasmuch as those new players took over from credit bank syndicates who could not afford anymore to sustain such high level and long duration projects on the basis of their shareholders' funds. Although credit banks are still involved in infrastructure finance, their role has shrunk to one of seed or bridge money for an initial period until long term capital can be secured by project promoters. This growing financialization of engineering explains why reputational risk (*Di Guardo, 2016*) has gradually overtaken most other corporate hazards on the eve of the largest infrastructure refurbishing about to take place in history across OECD countries.

The build-up of the P3 market – The Private-public partnership market started in the early 1990s with the Built-Operate-Transfer model in Australia and the Private finance initiative in the United Kingdom. Although P3 models varied significantly around the world with no clear standard recognized (*World Bank, 2016b*), the wave took off around 1995 to reach its peak in 2008, at the height of the GFC in the UK and most developed countries. However, it continued across emerging markets with a post 2012 slowdown, including in Chi

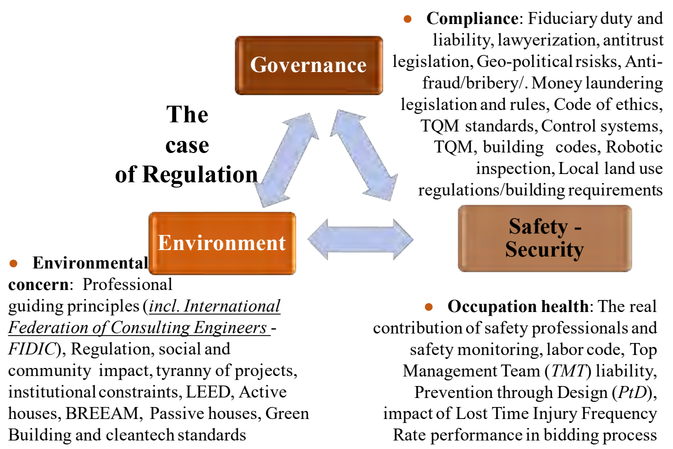


Figure 13 – The greatest lawyer of new regulation comes from the rising environmental concerns over climate warming Although the issue is well recognized by the AEC industry, a wide lack of information prevents the industry from reacting more pro-actively.

Over these 25 years, investment commitments totaled $1.5 trillion in over 5,000 infrastructure projects in 121 low- and middle-income countries (*World Bank, 2016a*), which enabled the top five countries (*Brazil, China, India, Mexico, and Turkey, whose market share of those investments varied between 81% in 2009 and 51% in 2015*) to forge and propel their own procurement industry on the international market. Hence, the P3 momentum triggered the real take-off of the PEF at the turn of the millennium and more actively since 2005.

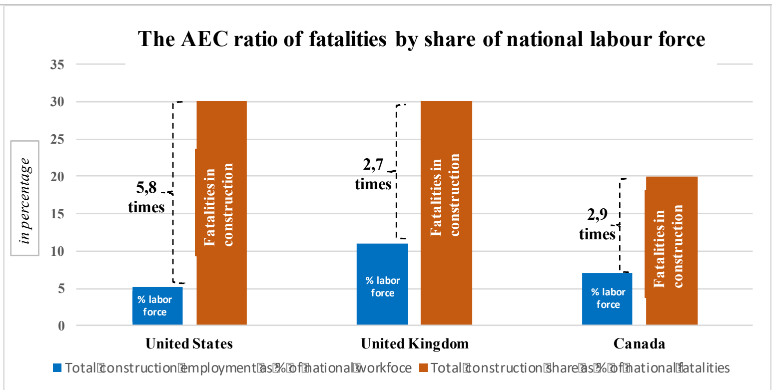


Figure 14: despite a substantial rise of safety professionals in the US construction industry, the ratio of fatalities in construction remains nearly 6 times as high as its share of the national labor force. (Source: "***The Value Proposition of the Safety Professional - Do Safety Professionals actually reduce fatalities?***", Dave Rebbitt, September 2012

The rise of a secondary market – The ability for pension funds, PEF and sovereign funds to exit projects at an advance or operational stage came with the emergence of an over-the-counter market, off official stock exchanges, in the UK. In practice, institutional investors don't need to wait anymore until a project is completed or becomes fully operational to liquidate their investments. Thanks to the growing popularity of infrastructure investing or what is called the 'real assets' investment class, there are enough investors in the market to take over the shares of those who need to exit for all kinds of reasons (*finding of a better opportunity, re-allocating their portfolio of assets, needing liquidity because of a corporate event, etc.*). This 'curb' or 'over-the-counter' market, away from established stock exchanges, has grown significantly in size to allow smooth exits at reasonable transaction costs. The density of the british PFI market and marketability of medium size projects eases the possibility of offering pieces of projects to third parties either directly, from hand to hand via a dealer, or by securitizing units of a project, the same way as other credit instruments (*mortgages, car loans and credit card liabilities*) are being offered by banks to institutional investors eager for higher yield opportunities than classic bonds. From 1998 through 2016, equity stakes in some 980 special purpose entities changed hands for an estimate of $ 20 billion (*Whitfield, 2016*). Based on 110 transactions involving some 277 infrastructure projects, the average yield stood at 28%, a slight drop from 29% for the period of 1998-2012. No wonder the Finnish project of Fortum Oyj in energy distribution managed to be sold for €2,5 billion in March 2014 at a multiple of 18 times its gross revenue before interest, taxes, depreciation and amortization.

The case of **Regulation and Governance** has left much less visible scars on AEC. Three areas are mostly concerned:

The environment – Environmental hazard is where regulation has increased the most since the turn of the millennium, especially as carbon emissions are concerned. It was found that a more stringent environmental regulation in AEC, measured by inspection frequency, provides a positive impulse for increasing investments in advanced technological equipment and innovative products and on business performance. Moreover, a well-designed "direct regulation" appears to be the most effective policy instrument for prompting the positive impact of environmental policies on innovation and intangible performance, while economic instruments do negatively affect business performance (*Testa et al., 2011*). On the other hand, the 1990 Amendments to the Clean Air Act on the U.S. Portland cement industry have significantly increased the sunk cost of entry, leading to a loss of between $810M and $3.2B in product market surplus (*Ryan, 2012*). Multilateral environmental accords, such as the late 2015 Paris climate agreement, and several recent legislation pieces and regulations [*the Canadian Environmental Assessment Act of 2012, US update of the Toxic Substances Control Act in 2016 - Bearden, 2013*] had a double and deep effect on compliance practices. While new and stiffer enforcement rules impose increasing cost on both risk control and operations, wide new business opportunities have emerged for environmental engineers involved in infrastructure construction.

Occupational health, safety and security –Safety hazards (*OHS*), the industry's most vulnerable flank with close to 100.000 fatalities (*Zhou 2013, Zhou 2015, ILO 2015*) per year around the world, is falling under increasing scrutiny both by public authorities and private industrial owners. Construction accounts for one in every six fatal accidents recorded at work annually (*ILO, 2015*). Further, the ILO estimates that the construction sector in industrialized countries employs between 6% and 10% of the workforce but accounts for between 25% and 40% of work-related deaths (*Lingard, 2013*). In industrialized countries, construction workers are 3 to 4 times more likely than other workers to die from accidents at work. In developing countries, the risks associated with construction work are estimated to be 3 to 6 times greater than in industrialized countries.

Fatal injuries in construction dropped in the US from a little over 1200 in 2006 to less than 800 in 2011 but have moved back to 937 in 2015 according to the Bureau of Labor Statistics, despite a fast rising population of safety professionals. The industry that complains most about over-regulation in OHS is the offshore oil and gas operators. Such bolt tightening, illustrated by the new culture regulators want to implement (*Kim, 2016*; *Sakurai, 2012*), the new European Construction (*Design and Management*) Regulations 2015 [V] (*CDMR*) and the international harmonization effect (*Eastern Europe, Middle East, Africa, Asia-Pacific and Latin America*) of the EN Eurocodes[VI],

[V] Replaces the CDM 2007 regulations and aiming to put a greater onus on the clients to think earlier about health and safety matters on construction projects and to encourage those with design responsibility to take better ownership of health and safety matters when schemes are first conceived, by solving the concerns whereby CDM coordinators were often perceived as peripheral with limited impact on design decisions, particularly at an early stage of the design process (*Anslow, 2015*).

[VI] The En Eurocodes, mandatory since 2010, are the ten European standards, developed by the European Committee for standardisation, specifying how structural design and other civil engineering works is spreading across the world, feeding a shadow economy (*Chancellor;15*) and affecting directly pre-qualification tender criteria that engineers and contractors must attain to win business. Such pressure combines with the growing integration of three ISO standards, 9001 (*quality management*), 14001 (*environment management*) and the new ISO 45001 safety standard (*previously known as occupational health and safety assessment series - OHSAS 18001, 1999 updated in 2007 to become obsolete in April 2021*) implemented in June 2018, by medium and large size AEC firms[VII]. Most smaller to medium firms will simply meet public owners' minimum requests for a 9001 standard of quality management, which also doubles up as a basic risk control mean[VIII]. Some relief came with electronic building permits and mobile inspection technology reducing approval rate by 30% and on-site inspection time by 25% (*WEF, 2018*).

Oddly enough, the greatest pressure for disclosure over occupational hazards performance comes from the private owners and industrial clients rather than from public-owned organizations or governments. According to several contracting sources, the cost of a fatality on a building site (*work stoppage, inspection period, recovery delay, insurance premium, litigation, etc.*) has become too high for the industry to bear. Another important reason outlined by lawyers and standard auditors is that an ISO certification lowers the liability of a firm by demonstrating that it took the necessary means to instill the right culture and prevent unsafe misconducts, even though its compliance system may not be adequate. One important reason is that a much larger share of variable cost contracts comes from the private sector (*specially the industrial one*) while most, if not all public-sector awards are made on fixed terms, under the lowest bid approach. Fixed price contracts transfer a much greater burden of risks to contracting firms than under variable cost arrangements, where owners bear a higher share of risk. Under such conditions, private owners are eager to exert a higher control on risk management. And since OHS ranks amongst the highest critical factors for a construction project (*Alzahrani 2013; Puri 2014*) and ranks first for all metrics in operational risk disclosed by the ACE industry, several metrics and disclosure formats such as the Total recordable injury rate (*TRIR*), lost-time incident[IX], personal injury frequency, dark rate, lost Workday Rate (*2 previous meanings under the US*

(*geotechnical aspects, structural fire design, situations including earthquakes, execution and temporary structures*) should be conducted with the EU with some 58 parts.

VII The 45001 standard is easier to implement than the previous OHSAS 18001 because of the upgrade of the 9001 and 14001 in 2015 from a process-based approach to a risk-based one. Those changes contributed to lighten the new standard, which is now expected to grow faster. As a general rule, most OHSAS 18001 AEC firm already has adopted the 9001 and 14001 standards. In Canada, SAI, which records 4000 OHSAS 18001 clients in North America, estimates the share of construction firms to be about 25% among a wide range of sectors (*Manufacturing, forestry, agriculture, etc.).* As for the share of all construction firms adhering to the OHSAS 18001 standard, it is estimated to be more or less 10%, concentrated among middle and large size companies (*from semi-structured interviews by the authors*).

VIII Interviews with small size engineering firms in Montreal, Canada by O'Neil 2017, which one of the present authors attended, confirms such practice.

IX The lost time injury frequency rate (*LTIFR*) is calculated using two numbers: the LTI within a given time frame, and the amount of hours worked in that time frame. For example, the LTIFR is calculated as follows per 1, 000, 000 hours for a quarter: 5 lost time injuries were recorded last quarter, and 1,584,391 hours were worked on construction sites. Then a) 5 X 1.000.000 = 5.000.000; b) 5.000.000 / 1.584.391 = 3.15, meaning that there were 3,15 lost time injuries every 1.000.000 hours worked last year.

Occupational Health & Safety Administration - OSHA) and fatality rate for direct and contract employees, are now required for pre-qualification purposes.

Compliance – The board of directors and Top Management Team (*TMT*) responsibility of large AEC corporations has grown significantly following the waves of mergers and acquisitions and cross-border expansion. As this section will demonstrate, the integration of fiduciary and stewardship models of design and contracting operations is making governance more complex and confusing with regards to the liability of the organization. The old model of pure consulting play, where the accountability of engineers could be well distinguished against that of contractors, has faded with the increased integration of consulting and contracting activities, fewer niche players and more sector diversity to reduce market risk (*Ye 2017*), creating more confusion in the market between the trusteeship and stewardship of large international groups.

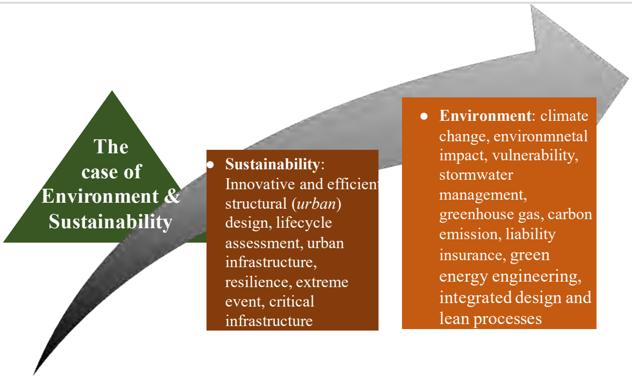


Figure 16 – Sustainability and environment go hand in hand with a string on interactions, both linked to the governance issue.

To some extent, such melding could be compared with the 1999 abolition of the US the Glass-Steagall Act to allow credit and investment banks to merge. The design fiduciaries (*the investment banks*), who regulate themselves through their professional code of conduct, merged with contractors (*the credit banks*) supervised by straight building codes, thus blending two different sets of culture, attitudes and risk management systems. Although the AEC industry complains about growing regulatory constraints, 26% of professionals feel that governments remain a most influential driver of innovation (*Ingram, 2016*), after customer demand (*including the State as a client*) and insider C-level officers. A case in point is the UK government, which is prioritizing BIM as part of its Digital Britain initiative (*Ingram, 2016*). Moreover, Loosemore (2014) argues that construction is a compliance-based sector with a long-tail of low performing firms which must be encouraged to change through regulation and legislation by prescribing minimum standards with incentives to innovate.

The case of **Environment and Sustainability** remains a major sticking point in the AEC industry, because of the “tyranny of the projects” or “project-based thinking”, as Koch (*2004*) suggested. As Berns et al. (*2009*) remind us, sustainability seems to change the AEC industry more than the industry is changing sustainability. Although the residential and commercial sectors use more than 40% of the US energy, structural engineers don’t seem to integrate sustainability into their choice of structural system.

A survey conducted in Oregon and Washington states by Rodriguez-Nikl et al. (*2015*) in 2010 indicates an important lack of information was a major barrier, with respondents requesting data that was standardized, current, reputable, and useful in the context of codes and standards. The quick pace of innovation was also identified as a challenge in obtaining adequate information. Results indicate that the client is the single most important influence on what a structural engineer can accomplish.

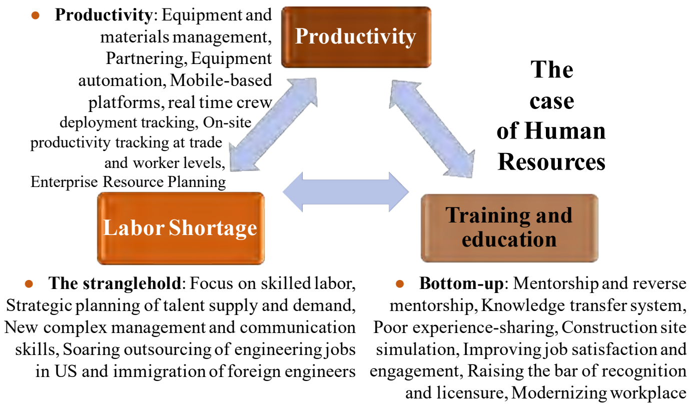


Figure 17 – Watching the rate at which North America is offshoring engineering services, either directly or via foreign affiliates of large multinational AEC groups, and raising the qualification bar for professional engineers, it is difficult to imagine how the continent will be able to soon reverse the manpower shortage.

The case of **Human Resources**: The enhancement of training and postgraduate requirements for recognized professional engineers, together with the resurgence of the infrastructure market in North America are reinforcing pressures on architect, engineer and skilled-labor supply to the point of harming productivity and project delivery.

Shortage: The infrastructure and urban development (*IU*) industry, with its main core of engineering and construction, employs about 100 million people worldwide *(>22 million engineers*). According to the US Chamber of Commerce, 95% of contractors have serious problems finding skilled workforce for their projects in 2017. Reuters ads that the construction worker shortage is at its highest since 2007. The Associated General Contractors claim that 86% of building firms aren't able to cover their severe workforce needs. Worse still, 56% of US contractors express doubt about the reliability of their current workforce because of a lack of training. The United Kingdom hard-to-fill vacancies have more than doubled since 2011. The industry has an entrenched gender gap, with women accounting for a mere 13% of the overall workforce and even less for senior management positions (*WEF, 2018*), even though such 'jobs in the construction industry can be done by women'(*Ness, 2012*). The share of employees who are aged 60 and older is increasing faster than any other age group while the share of employees under 30 is falling, according to the World Economic Forum (*WEF, 2017*). The workforce hovers around the 40-70 age bracket (*Ingram, 2016*).

Training and education: The popular perception of the industry has remained very low, with 11% of people in the UK viewing the industry as 'exciting' (*WEF, 2018*). Less than half of young workers and employers think education providers do an adequate job of preparing people for entry-level positions in the infrastructure and urban development industry. Stouffer (*2004*) reminds us that "engineers are not commonly perceived as creative professionals. A recent Harris Poll sponsored by the American Association of Engineering Societies and IEEE-USA found that "only 2 percent of the public associate the word 'invents' with engineering; [and] only 3 percent associate the word 'creative' with engineering" (*Bellinger 1998; Wulf 1998*)". "To remain competitive with international institutions and engineers, Stouffer adds, U.S. colleges and universities must foster creativity in their faculty and students… Incorporating creativity into student assignments promotes teamwork, communication, knowledge retention, ability to synthesize and make connections between courses and fields, and a smooth transition from formal education to practice."

Productivity: Rising cost pressures and constrained R&D budgets are driving the offshoring service trend. The global engineering services outsourcing (*ESO*) market, of which construction is still a tiny but fast growing part, is expected to reach USD 1.49 trillion by 2025, according to Grand View Research (*2017*). Companies prefer to outsource the service as it enhances efficiency, improves processes and lowers time to market products. On the tech-side, many AEC firms have begun incorporating new construction technologies into their daily activities, but most of their efforts only focused on software tools for digital collaboration. Such narrow interest can be explained by the struggle they had to wage to deploy new tools at scale with limited impact. The modest returns they've earned so far make these companies reluctant to explore additional productivity-enhancing technologies, especially those requiring substantial investment (*Blanco, 2017*). The McKinsey Global Institute (*Woetzel et al, 2014*) argues that innovations such as value engineering, standardized designs, and prefabricating components could encourage productivity and reduce construction costs by about 30% worldwide

The case of **Technology** and **Innovation**: A question of great importance is : Can the AEC industry truly profit from the tremendous technological breakthroughs that have occured over the last 10 years given the shortage of professional and skilled labour, and poorly informed and ill equipped sustainability measures ? A case in point is Arditi's claim (.) that techniques and especially foreign technology developments had little if no bearings at all on productivity. Four major areas have opened the door to a technical reshaping of the industry:

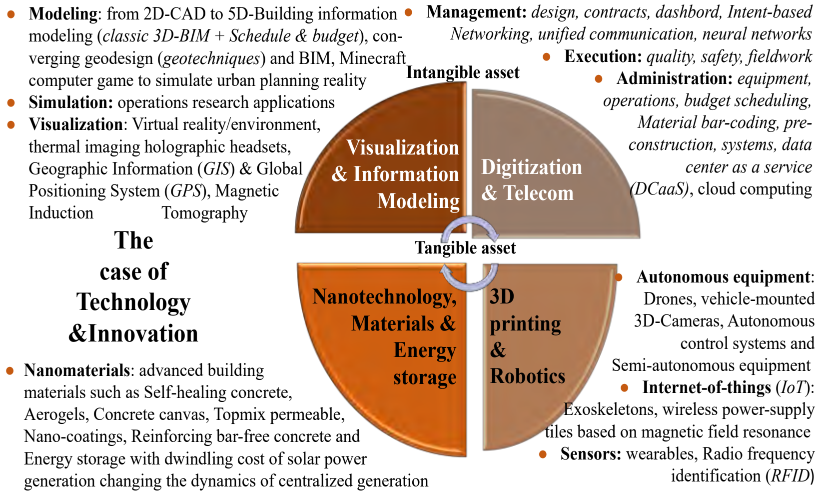


Figure 18 – The real issue here is whether the AEC industry can really take advantage of those new technology trends when integrating sustainability seems so difficult with a rising shortage of skilled and professional manpower.

a. **Digitization and telecom**: IT and data center delivering the right service, at the right pace, from the right provider, at the right price. Intent-based Networking involving pieces of networking software helping to plan, design and implement/operate networks and improve network availability and agility. **Unified communication integrates** mobile devices, remote devices, on-board devices or various information bits on these devices to amplify the productivity of today's 'Always-connected' and 'Always-collaborative' environment.

b. **3D printing and robotics**: Sensors to monitor traffic patterns, detect accidents and diagnose structural weaknesses, with video devices monitoring construction/operation sites, embedded devices and sensor wearing, wearable devices acting as amplifiers to augment, reinforce or restore human performance and prevent accidents and insure safety. Driverless trucks used at highway construction sites, as in Florida, or automate hauling, dozing and drilling as in mining and agriculture.

c. **Nanotechnology, materials and energy storage**: To replace traditional materials such as concrete, cement and asphalt, which make up most of the building demand. Nanomaterials are superstrong, ultra lightweight materials that can be substituted for steel reinforcement in structures and foundations, though still in a research stage. Induction Tomography and other geophysical technologies are rapidly improving the capability to "see" underground. These technologies will improve with the result of high quality underground surveys and cut into the riskiest part of any tunneling or excavation project. For instance, the hyperloop (*hyper fast low pressure transport modes*) projects in Canada, the US, Europe and China will rely heavily on tomography as well as on geotechniques to reduce the need of large and high-risk excavation and foundation work.

d. **Visualization and information modeling**: This is to assess design and project major infrastructure projects in a 180° model via “mixed” or “augmented reality”, as Bane NOR with St-Gobain did in Norway to familiarize the public way before the project start, or for planning complex medical and industrial projects. Geodesign involves design and planning methods that tightly couple the creation of design proposals with impact simulations informed by geographic contexts – BIM implements a continuous use of 3D digital CAD model over the full life cycle of a project - from design, through the planning and execution to operation and decommissioning.

IV- HOW INFRASTRUCTURE PROFESSIONALS PERCIEVE RISK

In order to connect the review of literature with the perception of practitioners, a survey, coupled with semi-structured interviews, was conducted in March 2017 among of the 10th Global Infrastructure Leadership Forum held in Montreal. The questionnaire (*see appendix 2*) was sent by e-mail and delivered by hand to 340 attendees. Out of the total, 90 responded providing a reasonable sample of 26%.
Engineering and construction firms (*E&C*) formed the largest group with 34%, with consultants second, owners third and financial institutions (*‘funders’, either commercial banks, investment banks or portfolio fund managers*) fourth among respondents. Survey participants served mostly North America, followed by Asia-Pacific and Europe (*see appendix 1 for details*). In terms of activities, transportation led the majority of respondants followed by oil and gas, electric power and social infrastructures. Operators of more than $1 billion led the way while funders with less than $5 billion responded most.

The main results of such soundings were as follows:
Rising risks on 2020 horizon: Political risks lead by far, followed by competition, market conditions and environmental constraints.

Most critical risks oversight in P3 model: Time and budget overruns rank nearly twice as high as the other critical risks

Leading contract models by 2020: The Design Build Finance Operate and Maintain (DBFOM), three times more than any other following model. The trend is very clear, with increasing suspicion towards traditional P3 and a rising preference for unsolicited infrastructure projects perceived to be easier to manage and control.

The fate of Greenfield project risks: Stable with a fair trend to rise, which confirms World Bank statistics.

Performance over the last 3 years: Less than half performed budget and timewise between 90 and 100% of the projects they handled.

Riskiest type of client: Public-owned organizations or Governments, yet the least sensitive client to occupational health. Indeed, the private owner sector is seen as extremely sensitive to health and accident hazards in project management, because of potential extra cost, delays and litigations.

Table 6 – Professionals projecting their favorite business model for 2020 through the survey. The integrated real asset management is voted the most popular.

5 Leading contractual models by 2020

- 65% **DBFOM** – *Design – build – finance – operate - manage*
- 25% **BD** – *Build and design*
- 22% **EPC** - *Engineer-Procure and Construct*
- *21%* **DBFO**

Key respondents are Funders (*67%*) with equally shared trend by E&C, Consultants and Owners (*53-56%*)

- *19%* **DBB** – *Design – bid - build*

Key respondents are Consultants 10% Funders 4% EC 9% Others 4%

Rising risks:

71% Political risks – *Change of government, unclear strategy /planning, protectionism, regulation* – with fair trend (*22%*) towards stability. At the time of the survey, the greatest uncertainty lied with the new presidency of the United States. Consultants were the most worried *(>88%*), followed by engineering and construction (*E&C >60%*), funders (*≈60%*), public /private owners (*59%*).

56% Competition – *Dwindling fees, more players, stiffer award conditions* – with strong trend towards stability (*38%*).

51% Market conditions – *Economy, volatile price of commodities/materials* – with great trend (*42%*) towards stability.

41% Environmental – *Increasing regulation, constraints and public reaction* – with strong trend (*35%*) towards stability.

Stable risk but rising trend:

48% HR recruitment (*craft labor/project manager*) with nearly as high probability of rising trend (*46%*). The greatest worries came from E&C and consultants (*52-53%*) and least (*42%*) from funders.

44% Excessive funding (*chasing too few good projects*) with strong trend to rise (*37%*) with widely shared concern by all sides (*41-44%*)

Stable risks:

54% Financial estimation forecasts with trend to rise (*35%*). The greatest concern came from consultants (*≈60%*), followed by owners and funders (*50%*) and least worried (*41%*) by E&C.

49% Corruption and fraud with strong declining (*33%*) trend. Here, the greatest worries over persistent *(=stable*) trend came from funders and owners (50%) with less pessimism from E&C (*stable at 41%*) and more optimism from consultants (*declining at 41%).*

Table 7 – How professionals perceive operational risks on site of an infrastructure

Type of most critical risks on site

Critical risks	Aggregate LOW priority (1+2)	Low priority-1	2	3	4	High priority-5	Aggregate HIGH priority (4+5)
Project delays, budget overrun	2,53%	0,00%	2,53%	8,86%	12,66%	73,42%	86,1%
Construction, technical, project mgt and complexity	**6,33%**	**2,53%**	**3,80%**	**18,99%**	**31,65%**	**43,04%**	**74,7%**
Design, implementation, commissioning, decommissioning	10,25%	1,28%	8,97%	26,92%	19,23%	42,31%	61,5%
Operations and maintenance	**16,46%**	**1,27%**	**15,19%**	**27,85%**	**34,18%**	**21,52%**	**55,7%**
Environment	20,78%	1,30%	19,48%	25,97%	28,57%	24,68%	53,3%

Declining risks:

37% Insufficient funding_with great stability (*40%*) trend. The greatest worries about persistent (*=stable*) shortage come from clients/owners with declining trends recorded by funders (*42%*), consultants and E&C (*35-37%*).

Overall, two major approaches appear for risk management. The first is a proactive stand, practiced by most respondents (*88%*), to try to uncover as many sources of risks as possible, with the strongest focus coming from owners and consultants (*71-73%*), followed by E&C (*58%*) and funders (*47%*). The second is a more reactive stand. Among those professionals who don't try to chase all forms of risks, 58% (*mostly engineers and construction practitioners*) focus rather on the weakest links of their organizations to prevent risks from hurting both project management and bottom line.

V- WOULD THE NEW AEC MODEL PLEASE RISE – A SYNTHESIS

Despite formidable sources of pressure, innovation within the AEC industry remains so far limited to management reshuffling, business consolidation and light telecom and digitization changes, especially in the area of OHS. Although 44% of firms claimed to be digitally enabled in 2017, their business was in fact a laggard in the adoption of digital technology and approaches to working, with 55% identified as 'exploratory', 'enhanced' or 'optimized' (*IFS, 2017*).

Twelve cases studies were drawn to illustrate the business models of major publicly listed AEC firms in Canada, the US, the UK, France and Australia. Those companies, operating in over 150 countries, had a total personnel of nearly 600,000 and combined sales of USD $153.6 billion stemming from a book of orders of USD180,3 billion in 2015. Those cases are the answer to the apparent contradiction between sudden growth and poor technology integration. Here is how McKinsey (*2014*) shows why the Chinese construction industry failed to take full advantage of technology advance:

a) The fast pace of infrastructure development, backed by pouring innovative financial and investment products, kept profits and thus, complacency high, just like what happened in the UK. "For the last decade, the industry has been sheltered by a healthy economy. This has enabled construction to prosper without having to strive for innovation" (*Wolstenholme, 2009*).
b) According to the World Bank (*2016*), some 530 PPP projects were undertaken between 1990 *($173 million*) and 2013 *($7.67 billion*) in China.
c) Excessive regulation of the industry and its supply chain, which discourages innovation and pushes AEC firms back to standard practice. Unlike western countries, specifications go as far as detailing the types of material to use and their level of thickness.

Table 6: Business model and profile of 12 major engineering groups

Companies	Leadership/ specialties	Home country	Personnel	Presence # countries	Sales	Orders	Shareholders' equity
All amounts in Euro, Canadian and Australian dollars were converted in million USD as of December 31, 2015, except for Australia where the fiscal calendar of Lendlease terminated on June 30 of 2016							
Aecom	World leader in architecture-engineering	USA	92.000	150	18.000	40.200	3.631
Aecon	Energy – mining infrastructure	Canada	12.000	3	2.095	2347	517
Balfour Beatty	Infrastructure	UK	34.000	10	10.293	16.280	1.228
CRH	Materials, procurement	Ireland	89.000	31	25.488	ND	14.628
Eiffage	Infrastructure/con-cession, construction	France	11.785	70	15.012	12.312	4.750
Fluor Corp.	Oil & gas, pharmaceutics	USA	38.758	> 80	18.114	44.726	3.113
IBI Group	World's 8th largest architectural group	Canada	2400	11	235	263	-11
Lendlease	2nd AUS engineering firm - property	Australia	30.000	12	11.165	15.318	4.154
SNC-Lavalin	1st CDA engineering firm, infrastructure, nuclear (Candu)	Canada	36.764	50	6.903	6.366	2.005
Stantec	Energy, water	Canada	15.000	6	1491	8.842	952
Vinci	Conessions, property	France	185.452	> 100	41.580	29.916	16.476
WSP	1st CDA pure play engineering firm	Canada	34.000	40	3230	3743	2030

The review of twelve international firms over a period of 20 to 50 years aimed to capture their shifting values across time and the key factors that led them to establish risk management processes following rapid growth and major compliance defects. *(Source: company financial statements, various financial analyst reports)*

FEATURES OF THE EMERGING MODEL

The key features of the new AEC enterprise are thus as follows:

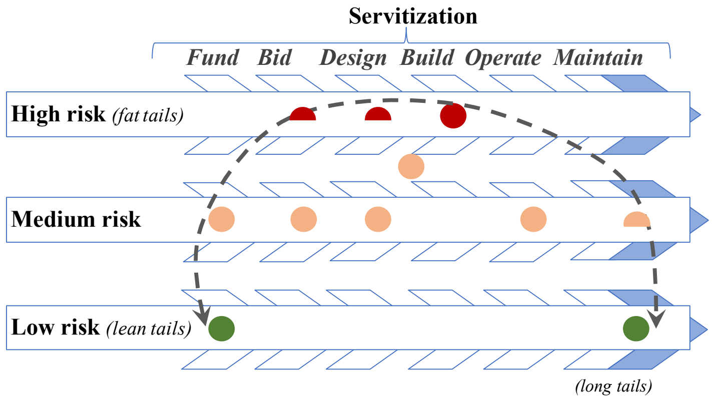
Integation and hierarchy:

from flat, agile and loose networks (*partnerships and joint ventures*) of the 1990s, the new design firm has become integrated into a more diversified organization. The US trigger in the 1980s of the design-build (DB) procurement model gained tremendous ground over nearly 40 years. Already, an analysis by Konchar (*1999*) showed that out of 351 real estate projects, 23% had moved from the design-bid-build (*DBB*) approach to the transition stage of construction management at risk (*CMaR*) and 44% had jumped the wagon for the design-build (*DB*). A unit cost comparison indicated that the DB method cost 4,5% less than CMaR and at least 6% less than DBB. From 1985 through 2000, the market share of DB over the traditional DBB approach grew from 12% to 35%, while the CMaR model jumped to 13% in 1990 but then dropped back to 10% and remained flat until 2015. From 2000 onwards, DB finally caught up with the classic DBB at 45%-45% in 2010 and then took the lead with 50% in 2015, according to the Design-Build Institute of America. Later on, a study (*Altus, 2007*) made for Infrastructure Ontario in 2007 went further by showing that the Design, Build, Finance & Maintain model squashed the traditional DBB approach for the owner in terms of risk.

a. The design coordination and completion risk dropped to almost nil with an absolute transfer to the project company;
b. Compared with a drop from 132.8% to 46.1% for life cycle and residual risk;
c. And from 51.5% to 0.3% for operational risks (*technological obsolescence, quality and unanticipated operating costs*) of the base cost (the operations portion of the contract for this category).

Fernane (*2011*) reviewed 77 public university buildings in the United States to find that DB projects significantly outperformed DBB projects in terms of Contract Award Cost Growth, Design and Construction Schedule Growth, Total Schedule Growth, Construction Intensity, Construction Change Order Cost Growth, and Total Change Order Cost Growth.

Smoothing out the tail risks straight through projects: Opting for a rinverted U curve



A straight through project management view of risk variation for six phases of AEC activities

Loss probability	Fund	Bid	Design	Build	Operate	Maintain
High		Real opportu-nity cost is double: gross cost is loss of a contract (*partial high risk*) with the reverse opera-tional risk of fraud, corrup-tion and abuse; net loss equals the cost of preparing the bid (*medium risk*) = ***No liability*** *and* ***short term risk***	Strong down-stream impact of errors and omissions on next 3 project phases. (*partial high risk*). As design is fiduciary in nature, liability is limited (*medium risk*) = ***Low liability*** *and* ***short term risk***	High operational risk of failures (*schedule delay, budget overrun, spec. deviations, etc.*) as steward = ***High liability*** *and* ***short term risk***		
Medium	Most of the engage-ment in equity is low due to the high leverage funding model of a project. When co-investors involved, AEC operates as fiduciary manager with no obligation of result = ***Low liability***				Lower operational risk dominate this phase with some managerial discre-tion (*fiduciary*) but mostly under strong stewardship. Medium to low liability for **Medium term risk**	Most maintenance & management systems are based on life-cycle cost minimization only, whereas greater managerial (fiduciary) discretion would allow for more innovation (*long term risk*) ***Medium to low liability***
Low						

Figure 19 – This illustration shows how the new AEC firm is trying to diversify market risk and run away from too much concentration on intrinsic (= *specific project*) risks. The reverse U-shaped curve outlined above, with corresponding probabilities defined in the table below, shows how the two tail-ends contribute in diversifying risks thanks to a straight-through project management approach. It parallels an equivalent reverse U-shaped model a PPP project undergoes with the initial increase of cost (*versus a public project*) due to the higher interest rate on funding and the later cost reduction resulting from the value contribution of greater expertise from the private interest (*Deng, 2016*).

Transactional costs have increased significantly from the traditional public procurement (TPP) to the PPP, to a point where the rise of unsolicited infrastructure projects coincides with a growing reluctance from AEC firms and their institutional funders to participate in open bid for PPP (*De Schepper, 2015, Rahman, 2010*). This is the new attitude of sovereign funds and major private equity players in infrastructures. A recent case is that of the Réseau Électrique Métropolitain (*REM*) in Montreal, Canada, to be owned, built and operated for an estimated price of CDN6.3 billion by the Caisse de dépôt et placement du Québec, a para-provincial government sovereign fund, which has the option but no obligation to exit the project company or to close a line that may not be profitable enough after 5 years and gave a buy-back option to the Quebec government after 50 years of operation.

The greatest influence the six pressure points have had on AEC firms is on the risk management, deriving from a very strong rise in risk awareness since the new millennium as a result of three major financial crises, and its subsequent decision-making process, which increasingly mix together on key options and strategy building.

Our findings reveal that the most critical areas of changes happened on three fronts:

First, the organizational model has changed and is increasingly represented by integrated consolidated firms operating from end to end, from financial targets to design, building, operations and maintenance. In short, construction engineering has become a soft industry leaving the hard building work to a world of ongoing small to medium-size firms and craftsmen teams increasingly specialized in the mobilization and management local project procurement. However, as several studies of Lu (*2014*), Jewell (*2014*), Ye (*2015*) outlined on the various aspects of diversification and consolidation of the AEC industry, such integration remains loose and the diversification strategy, both in terms of activities and subsidiary acquisitions, hardly entail full symmetry and full fledge synchronization among units of the same group.

Second, the split of the industry between soft horizontal (SH) and hard vertical (HV) work has helped to mature how risk is being managed. While corporate consolidation and systems integration enabled large and multinational enterprises (*LMNE*) to diversify their intrinsic (*specific project*) risks and adjust more comfortably to systemic (*market*) risks, much less change seem to have occurred amongst small to medium size enterprises (*SME*). The traditional frontier between what used to be identified as pure play (*strictly design engineering or strictly construction*) and integrated play is fading thanks to the extension of activities both upstream (*by getting involved in project finance*) and downstream (*in pursuit of servitization way beyond operations and maintenance*), which contributed to smooth out intrinsic fat tail risks *(where moderately extreme outcomes are more likely to happen than what might otherwise be expected from a normal risk distribution)* in construction. (*Wolstenholme, 2010; Robinson et al. 2016)*.

Third, such straight through project management approach is both a defensive act against high-end market risk, which characterized the 1998-2015 period of three major financial crises and instability and an offensive mean to compete on a more globalized market. If the organic and structure of the upper middle and high-end of the industry changed, not much seems to have happened on the process side. Otherwise, total factor productivity measures would have signaled more gains in added value. What really changed are new means of decision-making that emerged among large to multinational firms in selecting and managing their projects thanks to a wide range of new technology and intelligence systems. This is where the process side has changed most, either within organizations or on site. Among new decision-making most significant tools are the building information modeling, a pure digital technology advance coupled with data management and network communication to improve the supply chain management and the cost effectiveness of various operational phases, and the real options' approach, derived from the options securities market in the 1970s, to provide greater flexibility in managing uncertainty and measure management options and control cost.

FUTURE TRAJECTORIES OF THE AEC ORGANIZATIONS

The future possible trajectories liable to affect further a viable model for AEC firms are:

a) The increasing transfer of supply chain accountability (=*devolution*) to small and medium (*SME*) size enterprises to take advantage of their control over human resources.

b) By extending such control over a wider range of resources of all kinds, SME could be able to reduce the concentration of their exposure to high specific risks (*project risk*) by introducing some elements of servitization (*managing people, materials and local facilities during the construction phase*) and diversifying marginally their sources of income. Australia is a good example of such trend (*Bankwest, 2017*).

c) The shift towards an increasing trend of outsourcing real asset management execution, operation and maintenance by owners and promoters could further reduce resistance to innovation by providing greater discretion to LME under the servitization business model (Ivory, 2005).

VI- DISCUSSION, FUTURE RESEARCH, AND CONCLUSION

It is difficult to imagine a globalization slowdown, short of major political turmoils, the current model of large to multinational AEC enterprise (*LME*) will most likely pursue its growth trajectory to provide greater diversity of design, build, operate and maintain. However, in the shadow appears an increasingly strong and hungry new generation of stakeholders eager to acquire a growing piece of financial rent from the infrastructure world.

For behind the twelve leading corporations described in Table 6, appear major institutional investors locking in over 80% of equity that are pushing those players to go on expanding. Not unlike the Swiss company Nestlé, which has become an agro-food international investment fund outsourcing a growing share of its manufacturing to third parties, those firms may indeed become a sort of investment avatar, a reverse of the Macquarie model whereby engineers are taking over the investment side to direct project management across a multi-purpose AEC group, with the support of large institutional investors.

In short, via private equity channels far away from the better-known stock exchanges, institutional investors such as pension funds, university endowments, life insurance groups and country sovereign funds, assisted by family offices and hedge funds, will go on privatizing the universe of infrastructures to a point where Special Purpose

Entities will deal increasingly with users instead of taxpayers. The best illustration is the nascent investment funds creating by a wide range of AEC firms to ease their entry into mega and complex infrastructure projects. A cautionary tail is that of the case Enron (in the energy industry) nearly 20 years ago, whereby the engineering company operating gas pipelines gradually converted into a financial group that managed and operated various projects from which it extracted a wide range of financial derivatives, with all the conflicts of interest that it involved.

It is also important to consider the risk impact on humans and the environment when assessing the growing trend of financialization and servitization of infrastructure projects. First, as political geographer David Harvey notes (*2014*), in drawing attention to the rapid rate of development, “concrete is everywhere being poured at an unprecedented rate over the surface of planet earth”.

As projects become prevalent in large international markets (both financial and labor), knowledge transfers and flows of capital, it will become harder to assess the social and environmental impact these developments have on the livability of the urban environment. AEC firms may should consider evolving and developing mechanisms to foster community engagement and consider the impact on all stakeholders implicated in the projects undertaken.

Second, the rise of PPP often muddles the understanding of whether infrastructure and spaces in urban environments are public or private. The larger economic trend of privatization since the 1980s has seen a decline in publicly-owned or ‘common’ spaces. On a neighborhood level, we see this process already occurring through gentrification: building projects and improvements to infrastructure. The proliferation of ‘private’ public spaces, or para-public spaces, such as Google’s Sidewalk Labs in Toronto, malls in cities across the world and increasingly green spaces, results in a grey area where questions of governance, ownership, and land-use become murky.

Finally, an emerging emphasis and excitement with ‘smart city’ initiatives, for which infrastructure projects will be necessarily undertaken should raise concerns about how big data is used by cities, governments and private companies. As new technologies are deployed in public spaces (e.g. Wi-Fi), and innovative uses of already existing infrastructure are rolled out, it will be important to monitor the use of this data.

This article is in part, a postscript on the evolution of the world view on the AEC industry that was presented in a series of Horizon 2020 papers published on the wake of the re-engineering trends, the advent of the Internet, the promising future of Information Technology, the acute awareness of the fragmentation of the AEC industry with its ensuing impact on productivity and the wave of globalization in the late 1990s by Katsanis and Davidson when the industry was only starting a major consolidation. Nearly a generation later, a review of over 120 research papers summarizes the various pressure points liable to further alter the model of the AEC firm and provides a new perspective on likely trends. The AEC industry has become a true real asset investment class with its own financial markets and exchange platforms to a point where it has bent classic theories of structured capital and finance via the Special Purpose Entity vehicle. Risk awareness has become a key driver of decision-making across the industry, as it was observed by the first author during the 10^{th} and 11^{th} Global Infrastructure Leadership Forums held in Montreal in March of 2017 and 2018. The survey staged in 2017 already pinpointed some key directions in terms of servitization and risk perception. And though a wide range of new technology tools have appeared since the new millennium, the jury is still debating the value of their specific contribution to productivity and key performance.

In order to advance the research already presented in this this article the following areas research have been identified:

a) The quantitative census from the Google Scholar and ASCE knowledge databases (KB), although quite useful to detect mega-trends in research, needs to be fine-tuned to include a wider range of concerns such as: 'mergers and acquisitions', 'project finance', 'decision-making'. Furthermore, it would have been more meaningful for researchers to describe the core concerns expressed under each 5-year cascade to provide a sort of epistemological vision. This could have helped to measure better the current gap that prevails between the main academic preoccupations and the actual industry practice. Sure enough, both KBs are technologically biased by the limits of paper digitization and the legacy of the WorldWideWeb that started in the early 1990s. Even though both KBs continue to expand their coverage by digit-mining earlier years, what counted most for this research were the periods post 1990 and the wake-up (=breakout) trends that the two KBs uncovered.

b) A better synchronization between the quantitative census of research and the combination of semi-structured interviews and survey with practitioners might have contributed to shed more light over the time gap between the academic and professional worlds. It remains indeed difficult to estimate the time difference between prevailing ideas and innovations, both managerial and technical, in academic research and their implementation by the industry. Such asymmetry might explain the weak relevance of many Future/Vision/Horizon papers about what really happened some 15 to 20 years later.

c) Greater correlation should be tested between decision-making and processes used and the changes that occurred organically and structurally in the AEC industry, with more focus to differentiate design and construction professionals.

d) Better impact differentiation and evaluation could be made on the new AEC model between the six pressure points and their key components. For instance, did regulation influence more changes and adaptations of the AEC model than market forces and economic conditions? What is the real contribution of technology? How about the growing shortage of manpower?

One major lesson of what happened over the last 25 years is the grave neglect academics have shown towards the intrusive role of finance across the AEC industry.

Further study should also be carried out to distinguish the effect of fiduciarization (*the shifting of obligations of results into obligations of means*) on the AEC industry, on the assumption that design professionals (*the fiduciaries*) are taking over the building activity (*the stewards*) to secure a wider share of the rising attraction of the built-in/infrastructure economic rent.

New research should also look into the tremendous waves of mergers and acquisitions in order to attempt to establish an optimum balance of power between contractors and design professionals. As new roles are expected to ensue from increasingly large institutional investors the question is posed whether the new financial models are having an impact, positive or negative, on the new built environment, the sustainability of our infrastructures and the physical and economic welfare of individuals and society.

The case of Enron should never be neglected nor under-estimated, as its shadow casts dangerously over the future of the industry. Much research is needed in order to better underhand the intersection of the domains of engineering, procurement, construction, markets and finance if one wishes to comprehend and effectively manage the dynamics of the forces entrenched in these domains. to be done, but this is where our new AEC model has led us to.

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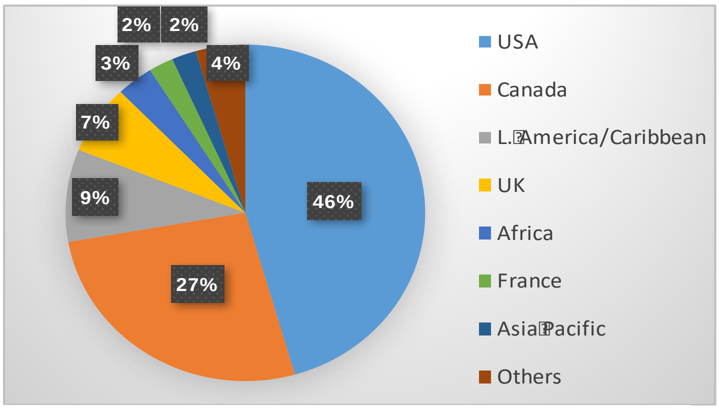
APPENDICES

Appendix 1 – Highlights of the 2017 Global Infrastructure Leadership Forum Survey

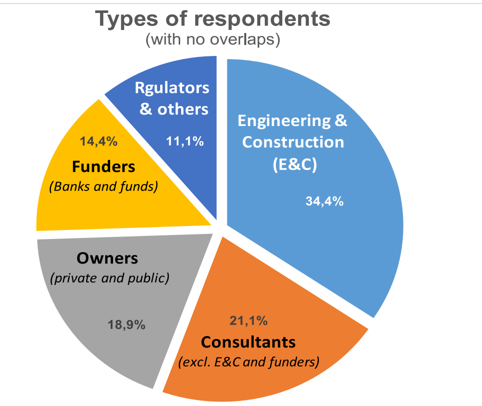
Survey Outline

- N. America leads in terms of respondents' origin – 73%, with Europe – 11% and S. America/Caribbean – 8% following



Survey Outline

- 90 participants ≈26% out of 340 listed attendees at the Global Infrastructure Leadership Forum



Leading contractual models
Who expects what by 2020

	E&C	CONSULTANTS	FUNDERS	OWNERS	REGULATORS/OTHERS	Expectation breakdown by contractual model				
Nb	31	19	13	17	10	% E&C	%C ONSULT	% FUNDERS	% OWNERS	% OWN
DBFOM	15	9	8	10	18	48%	47%	62%	59%	180%
DBOT	7	1	3	3	0	23%	5%	23%	18%	0%
DCMF	4	2	1	1	2	13%	11%	8%	6%	20%
DBB	6	5	1	3	0	19%	26%	8%	18%	0%
DBFO	5	3	4	4	0	16%	16%	31%	24%	0%
BF	1	1	2	0	0	3%	5%	15%	0%	0%
BOM	1	3	1	2	4	3%	16%	8%	12%	40%
BOO	2	1	1	2	4	6%	5%	8%	12%	40%
BD	7	5	1	2	4	23%	26%	8%	12%	40%
BOT	3	0	3	1	3	10%	0%	23%	6%	30%
BOOT	3	2	0	5	1	10%	11%	0%	29%	10%
BLT	1	2	0	4	1	3%	11%	0%	24%	10%
BBO	2	2	0	4	0	6%	11%	0%	24%	0%
EPC	7	4	0	1	5	23%	21%	0%	6%	50%
LSC	4	7	0	1	4	13%	37%	0%	6%	40%
OM	0	3	0	4	1	0%	16%	0%	24%	10%
VPC	1	0	0	0	1	3%	0%	0%	0%	10%

Appendix 2 - Vision 2020 - Infrastructure Risk Survey

10th Global Infrastructure Leadership Forum – Montreal 2017

This survey is intended to capture the participants' perception regarding where risks lie by 2020. This 5 minutes survey will help us aggregate your answers and deliver the results tomorrow afternoon. The survey is conducted by postgraduate students in governance and engineering of the École de technologie supérieure (*ÉTS*) in cooperation with GCLA, the Forum organizers. Your answers will be anonymous. Your opinion as practitioner is critical to us and we are thankful to you for filling it either on paper or through the email addressed to you personally last night. If you choose to answer through the web, would you please send your answers not later than 9h00 Thursday morning.

1-GENERAL PROFILE

a-In which CITY are your headquarters established: ____

b-Leading activity of the organization you represent (*please tick*)**:**

Engineering: ☐	Construction: ☐	Consultant: ☐	Materials: ☐
Credit/Investment bank: ☐	Pension funds: ☐	PE/InfraFund: ☐	Other fund/endowment: ☐
Private Owner/client: ☐	Public/Govt Owner/client: ☐	Regulator: ☐	OTHER: ☐

c-Which sector do you serve the most as funder and/or operator?
(Use numbers from **5** – *Greatest focus* – to **0** – *none*)

General building (GB): __	Manufacturing (MNF): __	Electric Power (PW): __	Sewerage / solid waste (SSW): __
Industrial process/ petroleum (IPP): __	Hazardous waste (HW): __	Telecommunications (TC): __	Energy (*oil, gaz, renewables*): __
Water supply/ treatment: __	Transportation *(road, bridge, tunnel, airport, port)*: __	Social *(health, education, public services)*: __	Defense: __

d- Which region do you mostly intervene in ? (*please tick* - **Maximum 3 choices)**

Developed countries: ➡	North America: ☐	Western Europe: ☐	Japan-Australia-NZ: ☐
Emerging markets: ➡	Africa: ☐	India-China: ☐	Eastern Europe/Russia: ☐
	Gulf-Middle East: ☐	South East Asia: ☐	Latin America: ☐

e-What is the size of your company in M$ (*please tick*)**?**

For operators Turnover < $100 ☐ $100-250M ☐ $250-500 ☐ $500-1000M ☐ $1000-2500M ☐ > $2,5B: ☐

For funders Assets < $5B: ☐ $5-25B: ☐ $25-100B: ☐ $100-500B: ☐ > 500B: ☐

2-WHAT TO EXPECT IN TERMS OF RISKS

a-Which risk/uncertainty do you see rising/declining over the next 3 years (*please tick*)**?**

Risk or uncertainty by type	**Declining**	**Stable**	**Rising**
Political (*change of govt, unclear strategy/planning, protectionism, regulation*)			
Market conditions (*economy, volatile price of commodities/materials*)			
Competition (*dwindling fees, more players, stiffer award conditions*)			
Funding (*too much money chasing too few good projects, pushing yields down*)			
Funding (*too little money chasing too many projects, more greenfields than brownfields*)			
Financial estimation / forecasts (*due to complexity + management shortage*)			

HR recruitment of craft labor and/or project manager			
Environmental (*Increasing regulation, constraints and public reaction*)			
Corruption (*fraud, misappropriation, bribery, etc.*)			

b- Please rate by priority the critical risks you usually measure for either conventional or P3 projects

TYPE OF RISK	1 = Low priority	2	3	4	5= High priority	Unsure/ Don't know
Project delays, budget overrun						
Supply, procurement security						
Design, implementation, commissioning, decommissioning						
Occupational Health and Safety						
Assets misappropriation						
Compliance, specifications						
Environment						
Technological disruption ***(absorbing Innovation)***						
Construction/technical/project management ***(due to rising project complexity)***						
Labor relation						
Operations and maintenance						

c-Does your organization try to list all possible/probable risks it faces during a project? Yes ▯ **No** ▯
If No, do you try to uncover and protect the weakest links/units of your operation chain? Yes ▯ **No** ▯

d-Tick the 3 contract models that you believe will dominate the market over the next 3 years (*please tick***)?**

Design Build Finance Operate and Maintain (DBFOM)		Build Operate and Transfer (BOT)	
Design Build operate and transfer (DBOT)		Build Own Operate and Transfer (BOOT)	
Design Construct Maintain and Finance (DCMF)		Build Lease and Transfer (BLT)	
Design Bill Build (DBB)		Buy Build and Operate (BBO)	
Design Build Finance and Operate (DBFO)		Engineer-Procure and Construct (EPC)	
Build and Finance (BF)		Lump sum contract (LSC)	
Build Operate and maintain (BOM)		Operate and Maintain (OM)	
Build Own and Operate (BOO)		Variable price contract (VPC)	
Build and Design (BD)			

e- Over the next 3 years, will Greenfield project risks tend to: Decline ▯ Stable ▯ Rise ▯

f- Over the last 3 years how well did you perform on most of your projects?
Timewise: ≤75% ▯ 75- 90% ▯ 90- 100% ▯
Does not apply ▯

Budgetwise: ≤75% ▯ 75- 90% ▯ 90- 100% ▯
Does not apply ▯

g- What is the riskiest type of client/owner (*please tick***)?:** Public/Govt ▯ Private/Industrial ▯ No difference ▯

h- Which client/owner is more demanding on the issue of occupational health-safety on site?

Public/Govt ▯ Private/Industrial ▯ No difference ▯

i- How will the equity share in a project evolve towards over the next 3 years?
10% ▯ 20% ▯ 30% ▯ Depends on the sector ▯ General decline ▯

j- Could the moving discount rate affect the risk / value for money assessment over the next 3 years?
Yes ▯ **No** ▯ **Uncertain** ▯ **Don't know** ▯

NOTES ON RESEARCH METHODOLOGY

Quantification of research on four combinations of three key words paired with 'Risk' appearing in Google Scholar and the ASCE Library between 1966 and 2015

Four combinations of key words were used to track down the emergence of research in 'Risk' since 1966 to link up with the study of Edwards, 1998. The various combinations reveal both the size of the concern [*example: 1.420.000 papers in 2011-2015 in Google Scholar for construction and risk vs 74.000 when two categories* (civil engineering and construction) *are paired with risk*)] and the timing and speed of awareness (*growth since the break-out year – Example: CAGR of 108,78% from 39.000 to 741.000 for the pair of 'infrastructure' and 'Risk', marking a sudden awakening in the early 1990s with 4 periods until 2011-2015*). CAGR measures were set on the basis of 5-year periods instead of by single years. The breakout year was defined under two criteria when: 1) the value progression exceeded 75% and reached/exceeded generally 100%, until the end of the series in 2011-2015; 2) the exponential growth became persistent. The compounded average growth rate (*CAGR*) was calculated from the break-out year (*outlined in yellow for each column*).Values under Google Scholar are all in thousands of research papers, whereas numbers under the ASCE library are in units. Google Scholar represents a more generalist universe of academics, offering a wider spread of issues and concerns, with however a much greater corresponding noise effect, while the ASCE library is more focused and representative of the design and construction academics and practitioners. Period of computation Period of computation: May 2, 2018, excluding patents and citations for Google Scholar.

Google Scholar Time Periods *(excl.patents + citations)*	**Construction & Risk** *(GS in '000)*	**Infrastructure & Rsk** *(GS in '000)*	**Civil engineering & Risk** *(GS in '000)*	**Civil engineering & Construction & Risk** *(GS in '000)*
1966-1970	17,7	2,5	3,82	2,25
1971-1975	19,8	3,66	5,41	3,58
1976-1980	25,8	9,41	9,44	5
1981-1985	35,9	15,1	12	8
1986-1990	94,2	20,5	16,3	12,4
1991-1995	152	39	24,2	16,8
1996-2000	508	122	38,4	25
2001-2005	889	278	94,8	47,7
2006-2010	1460	685	160	79,3
2011-2015	1420	741	252	74
Compounded avg growth rate	**72,05%**	**108,78%**	**87,22%**	**24,55%**
	Signals a break-out when the delta jumps by about 100%			
ASCE Time Periods	**Construction & Risk** *(ASCE in units)*	**Infrastructure & Risk** *(ASCE in units)*	**Civil engineering & Risk** *(ASCE in units)*	**Civil engineering & Construction & Risk** *(ASCE in unit)*
1966-1970	19	0	12	6
1971-1975	17	2	13	7
1976-1980	31	2	23	14
1981-1985	363	58	289	214
1986-1990	879	176	651	498
1991-1995	1138	267	834	665
1996-2000	2320	718	1586	1256
2001-2005	3927	1717	3496	2571
2006-2010	6305	3008	5385	4073
2011-2015	8748	5502	7807	6069
Compounded avg growth rate	**69,95%**	**113,56%**	**73,22%**	**138,07%**

Quantification of research on four combinations of three key words paired with 'Finance' appearing in Google Scholar and the ASCE Library between 1966 and 2015

Four combinations of key words were used to track down the emergence of research in 'Finance' since 1966 to link up with the study of Edwards, 1998. The various combinations reveal both the size of the concern [*example: 589.000 papers in 2011-2015 in Google Scholar for construction and finance vs 34.500 when two categories* (civil engineering and construction) *are paired with finance*)] and the timing and speed of awareness (*growth since the break-out year – Example: CAGR 143,2% for only 2 periods under the pair of 'Civil engineering' and 'Finance' from the break-out year of 2001-2005 through 2011-2015*). CAGR measures were set on the basis of 5-year periods instead of by single years. The breakout year was defined under two criteria when: 1) the value progression exceeded 75% and reached/exceeded generally 100%, until the end of the series in 2011-2015; 2) the exponential growth became persistent. The compounded average growth rate (*CAGR*) was calculated from the break-out year (*outlined in yellow for each column*). Values under Google Scholar are all in thousands of research papers, whereas numbers under the ASCE library are in units. Google Scholar represents a more generalist universe of academics, offering a wider spread of issues and concerns, with however a much greater corresponding noise effect, while the ASCE library is more focused and representative of the design and construction academics and practitioners. Period of computation: May 2, 2018, excluding patents and citations for Google Scholar.

Google Scholar Time Periods *(excl.patents + citations)*	Construction & finance *(GS in '000)*	Infrastructure & finance *(GS in '000)*	Civil engineering & Finance *(GS in '000)*	Civil engineering & Construction & Finance *(GS in '000)*
1966-1970	15,6	28,1	3,79	2,33
1971-1975	16,2	14,6	5,27	2,93
1976-1980	19,2	27,5	6,48	3,93
1981-1985	20,8	21,2	7,98	4,55
1986-1990	33,9	34,6	11,3	7,1
1991-1995	79,2	58,9	15,4	10,8
1996-2000	169	123	21,3	15,8
2001-2005	303	181	46,6	25,4
2006-2010	723	320	57,4	37,2
2011-2015	589	292	126	34,5
Compounded avg growth rate	**65,14%**	**49,22%**	**143,22%**	**37,19%**
	Signals a break-out when the delta jumps by about 100%			
ASCE Time Periods	**Construction & FIN** *(ASCE in units)*	**Infrastructure & FIN** *(ASCE in units)*	**Civil engineering & FIN** *(ASCE in units)*	**Civil engineering & Construction & FIN** *(ASCE in units)*
1966-1970	13	0	8	5
1971-1975	23	2	19	13
1976-1980	33	3	17	12
1981-1985	343	72	274	209
1986-1990	764	226	581	458
1991-1995	1095	298	813	651
1996-2000	1817	617	1180	977
2001-2005	2811	1342	2592	2060
2006-2010	4410	2223	3954	3104
2011-2015	5708	3077	4132	4132
Compounded avg growth rate	**59,78%**	**86,98%**	**57,18%**	**64,44%**

Quantification of research on three combinations of three key words paired with 'Market Risk' appearing in Google Scholar and the ASCE Library between 1966 and 2015

Four combinations of key words were used to track down the emergence of research in 'Market Risk' since 1966 to link up with the study of Edwards, 1998. 'Market risk' (*also known as systematic risk*) may sound redundant with the more generic notion of 'Risk', but outlines in fact the reverse of the concept of specific or intrinsic risk that a single construction project represents. The tracking of 'Market Risk' over time singles out the growing awareness of the need to diversify organically, geographically or financially to avoid too much concentration on a single basket of specific risks, as to avoid putting too many eggs in a single basket. The various combinations reveal both the size of the concern [*example: 611.000 papers in 2011-2015 in Google Scholar for 'Construction' and '(Market risk)' vs six times less -108.000 when two categories* ('Construction' and 'Infrastructure') *are lumped together with '(Market risk)'*] and the timing and speed of awareness (*growth since the break-out year – Example: CAGR 36,32% for 6 periods under the pair of 'Civil engineering' and '(Market risk)' from the break-out year of 1981-1985 through 2011-2015*). CAGR measures were set on the basis of 5-year periods instead of by single years. The breakout year was defined under two criteria when: 1) the value progression exceeded 75% and reached/exceeded generally 100%, until the end of the series in 2011-2015; 2) the exponential growth became persistent. The compounded average growth rate (*CAGR*) was calculated from the break-out year (*outlined in yellow for each column*). Values under Google Scholar are all in thousands of research papers, whereas numbers under the ASCE library are in units. Google Scholar represents a more generalist universe of academics, offering a wider spread of issues and concerns, with however a much greater corresponding noise effect, while the ASCE library is more focused and representative of the design and construction academics and practitioners. Period of computation: May 3, 2018, excluding patents and citations for Google Scholar.

Google Scholar Time Periods (excl.patents + citations)	**Construction & (Market Risk)** *(GS in '000)*	**Construction & Infrastructure & (Market Risk)** *(GS in '000)*	**Civil engineering & (Market Risk)** *(GS in '000)*	**Civil engineering & Construction & (Market Risk)** *(GS in '000)*
1966-1970	8,66	0,5	0,016	1,51
1971-1975	13,8	1,15	3,15	2,12
1976-1980	17,2	2,52	4,35	3,03
1981-1985	18,6	4,74	7,37	4,2
1986-1990	30,4	8,36	12	7,87
1991-1995	75	16,9	16,5	12,9
1996-2000	118	32,6	21	17,1
2001-2005	311	68,3	37,2	22,1
2006-2010	679	97,4	46,6	33,6
2011-2015	611	108	47,3	28
Compounded avg growth rate	**82,24%**	**71,06%**	**36,32%**	**28,90%**
	Signals a break-out when the delta jumps by about 100%			
ASCE Time Periods	**Construction & (Market Risk)** *(ASCE in units)*	**Construction & Infrastructure & (Market Risk)** *(ASCE in units)*	**Civil engineering & (Market Risk)** *(ASCE in units)*	**Civil engineering & Construction & (Market Risk)** *(ASCE in units)*
1966-1970	1	0	0	0
1971-1975	1	0	0	0
1976-1980	1	0	0	0
1981-1985	58	15	1	1
1986-1990	223	53	2	2
1991-1995	278	92	2	1
1996-2000	608	236	3	3
2001-2005	753	369	16	13
2006-2010	1216	627	18	14
2011-2015	1832	978	31	30
Compounded avg growth rate	**52,38%**	**79,15%**	**39,19%**	**115,44%**