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Are Megaprojects Ready for the 4th Industrial Revolution?

David Whitmore CEng, FIMechE, AMAPM
Head of Energy,
Pcubed,
London
Contact: +44 7834 505696 david.whtimore@pcubed.com

Dr. Eleni Papadonikolaki ARB MAPM
Lecturer in Building Information Modelling & Management
The Bartlett School of Construction & Project Management,
University College London
orcid.org/0000-0003-1952-1570

Dr. Ilias Krystallis AMAPM
Lecturer in Enterprise Management
The Bartlett School of Construction & Project Management,
University College London
orcid.org/0000-0001-7687-831X

Professor Giorgio Locatelli PhD CEng FHEA
Chair in Project Business Strategy
School of Civil Engineering - University of Leeds
orcid.org/0000-0001-9986-2249

Abstract

Complex Projects and Megaprojects are increasingly shaped by new enabling technologies and new demands from businesses including how people are treated when working on these endeavours. This is often referred to as the Fourth Industrial Revolution (4IR). Project leaders and practitioners are not fully leveraging the opportunities unlocked by the 4IR and project performance shows little signs of improvement despite the highly innovative and collaborative environment that the 4IR stimulates. This paper discusses this challenge and concludes that a significant reason why these benefits are not being realised is because there is a competence gap in both the project leader and practitioner communities. These communities are attempting to deal with 21st Century issues using competences, toolsets and a mindset created 100 years' ago. Significant development in competences associated with the 4IR in general are required. In this paper specific competences are proposed and justified: collaborative working including people, process and digital components, lean six sigma and agile. Success will be to empower the people who deliver Megaprojects such that they are able to deliver the planned social value to all stakeholders involved.

Keywords: Megaproject, digitalisation, lean start-up, agile, design thinking, collaboration

INTRODUCTION

The world of project management is being impacted by two major disruptions in the workplace: firstly digital technology is changing the social and collaborative environment in which projects are delivered; secondly the change in public attitudes to human-centred factors such as equality, diversity, inclusion, mental-health and wellbeing means that many autocratic project management principles are no longer compatible with the zeitgeist of the modern business world. These two factors contribute to the 4th industrial Revolution (4IR) that is creating a new way of working for the 21st Century. This should inspire a positive shift in project planning, delivery and operational performance. Greater collaboration enabled by digital tools should stimulate innovation and speed up decision-making resulting in the ability to react faster to changes and risks. The ability to fully utilise all the knowledge of a diverse set of people who feel more able to contribute should also foster a similar improvement in innovation and avoid “group-think” failures (Greco, 2017). However, there is limited evidence that project performance is showing any significant improvement and many projects continue to exhibit abject performance metrics (Locatelli, 2018).

There is extensive debate in the literature about the performance of Megaprojects. Using the Iron triangle as a model (performance in terms of cost/budget, schedule/time, quality/scope) there are different perspectives. Merrow analyses 318 Megaprojects showing how the majority are delivered consistently over budget and late (Merrow, 2011). Locatelli scrutinised 30 transportation infrastructure Megaprojects showing how the majority are delivered over budget and late (Locatelli, et al., 2017). However, the literature shows that there are also Megaprojects that delivered reasonable time and budget performance such as the Rotterdam metro extension (Giezen, 2012). Recently, there has been a vivid debate in the literature (Flyvbjerg, 2018), (Flyvbjerg, 2019) and (Love, et al., 2019) about the extent of overruns and delays in Megaprojects as well as the reasons.

Most projects reviewed or experienced by the authors are still delivered in a very conventional way using traditional project management tools, competences and mindsets. This results in a failure to create a modern environment in which the two disruptions (digital technology and human-centred operating models) can thrive and deliver benefit. Therefore, there is little noticeable change in project management performance despite the significant steps forward in the business environment. Traditional project management tools and competences were mostly codified 100 years’ ago (Taylor, 1911), (Fayol, 1916) and (Gantt, 1919) and were developed for a non-digital/machine-centred world.

Modern management tools and techniques can support the development of collaborative environments where people can use the full range of their skills to maximise the chance of project success. Approaches such as lean (Locatelli, 2013), six-sigma (Parast, 2011), systems engineering (Locatelli, et al., 2014) and agile (Serrador & Pinto, 2015) have all been developed mostly outside the project management environment over the last quarter of the 20th century and early 21st. These techniques focus on collaboration, innovation, discovery of requirements and they value the innovative unpredictability of the human being. There is remarkable evidence that adoption of some of these techniques produce significant improvements in a project's delivery performance. Saab's development programme for its Gripen E fighter jet was established in a fully agile environment, using Agile techniques, and the results have been dramatic with all performance parameters exceeding the competitor Lockheed programme (Furuhjelm, et al., 2017).

This paper will show that there are a set of technical competences in addition to the traditional project management "toolbox" that are required by those leading and delivering Megaprojects in the 4IR world. This will be demonstrated by examining how these competences are used by teams working in other sectors that are successfully using 4IR technologies and assessing their relevance to Megaprojects. By developing these competences project leaders and practitioners will be able to understand and therefore derive the potential benefits of using 4IR technologies and methodologies on Megaprojects. This in turn will stimulate enhanced project performance more aligned to the benefits being accrued in other industrial and commercial sectors.

BACKGROUND TO THE FOURTH INDUSTRIAL REVOLUTION (4IR)

The 4IR relies on a well-connected 'digital thread', a seamless flow of data from design to production (Cotteleer, et al., 2016). Etymologically, the term 'digital' refers to using or storing data or information and it has come to represent the key enabler of 4IR. To this end, various digital technologies shape the *digitisation* of data in businesses and projects, which in turn allows for *digitalisation* of the associated processes, towards the eventual *digital transformation* of the industry, and competences required that enable and improve the efficiency of the work (Papadonikolaki, 2020). *Digitisation* refers to the transfer of information from analogue to digital, whereas, *digitalisation* refers to the process of changing manually transacted business to digitally automated business (Gartner, 2013), (Ross, 2017). According to the Institution of Civil Engineers (ICE, 2017) digital transformation is:

"the application of digital technologies to all aspects of human life. [In this report] it applies to the wholesale changes in how our industry designs, builds, operates, maintains and decommissions assets. It also refers to the transformation of how we value data, and the impacts upon processes and systems, and ultimately decision making."

A useful concept for understanding the challenges posed by the 4IR and digital transformation is the 'Digital Vortex'. The Digital vortex describes how digital technologies are forcing a change (disruption) in business practices in such a way that no business sector will escape its disruptive effects (Wade, et al., 2017). It can be thought of as the inevitable movement of industry actors toward a digital centre in which their business models and value chains are digitised to the maximum extent possible (Bradley, et al., 2015). (Christensen, 2013) defined disruption as a process characterised by radical and rapid change and it is often driven by technological innovation. Incumbent organizations who fail to respond to digital change are replaced by new entrants (Christensen, 2013). Moreover, industry architectures often change significantly (Henderson, 1990) and digital becomes a core competence of the business rather than a bolt-on (Gill, 2016). A report by the Global Centre for Digital Business Transformation, through an IMD and Cisco initiative revealed that executives are increasingly recognizing the positive aspects of digital disruption (Wade, et al., 2017). Digital disruption is growing across industrial sectors and has gathered significant traction (Wade, et al., 2017). This study found that the average time to disruption, that is a "substantial change" in market share among incumbents, was as little as 2-3 years and is accelerating.

The construction sector is also on the verge of being disrupted by the Digital Vortex (Bradley, et al., 2015). Until now, the asset-heavy, business-to-business industries in the outer rim of the Digital Vortex have had little cause to worry about digital disruption. However, recent evidence suggests that these industries can be quickly pulled into the centre of the Vortex. The transportation and logistics industry, for instance, is under enormous pressure from technologies such as self-driving cars, electric vehicles, and disruptors such as Amazon Logistics and Uber (Manners-Bell & Lyon, 2019). The healthcare and energy industries similarly face competitive pressures from non-traditional sources (Schwab, 2017). These industries are beginning to take the threat of digital disruption seriously, as evidenced by their investments in new business models, digital capabilities, and digital competences (Figure 1).

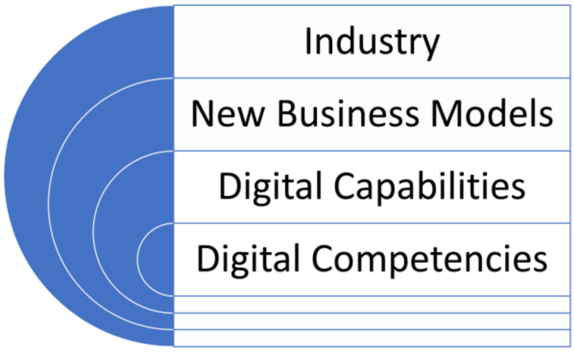

Figure 1: Industries safeguarding themselves against digital disruption

The response of the most successful companies to life and business in the Digital Vortex is to adopt new ways of working, which puts people at the centre. Increasing the speed of feedback from the customer, curating data, resulting in more informed decision making and enabling rapid change even to products currently in production. This is called Digital Business Agility (Wade, et al., 2017).

Wade further shows evidence that large infrastructure projects are being disrupted by digital technologies and are developing business agility to address it (Wade, et al., 2017). More effort is needed at the onset of the project to design a bespoke organisation (or delivery model) to embrace the 4IR benefits. A recent study systematically found that digital information transforms project delivery models (Whyte, 2019). Using Megaprojects as context, the study identified transformations related to knowledge codification and the transition from paper documentation to digital workflows. By scrutinising three Megaprojects delivered in the UK, it identified three variations of project delivery models and how the relationships between client and supply chain are dictated in digitally enabled project delivery. These models are focused on 1. Owner-operator, 2. Pop-up client, and 3. Integrated pop-up client. These models describe how changing supply chains and relationships with owners, operators, and end users in digitally enabled project delivery are addressed. In addition, new generations of integrated solutions were observed, showing how project deliverables, supplier interactions, and relationships with owners, supply chain and end users transform. This transformation is due to the digital information becoming a deliverable. The findings corroborate the findings of an earlier study which found that working in a digitally enabled project environment drives towards life-cycle operation information and ensures knowledge transfer access all project phases (Krystallis, et al., 2015).

Westerman found that businesses not only require digital initiatives, but also high competences in transformation management to enable them to outperform others in revenue generation, profitability and market valuation (Westerman, et al., 2012). Business leaders position themselves for future success and power up their teams with new digital competences. Gill asserts that five digital competences are important in the wake of the 4IR: product ownership, customer-centric design, communication, digital governance, and data science (Gill, 2016).

This "Digital Business Agility" is the essential factor that enables organisations to react and reform themselves during disruption caused by the Digital Vortex. Considering the above, what 4IR competences do the project leaders and practitioners require to develop Digital Business Agility in their project environments? The remainder of this paper seeks to answer this question. *Note that in this context the project leader is that person responsible for meeting the strategic objectives for the project and the practitioners are those that use project management methodologies to deliver the project.*

DIGITAL BUSINESS AGILITY AND MEGAPROJECT MANAGEMENT COMPETENCES

A Megaproject can be conceptualised as an extremely large and complex living organisation that is characterised by three properties. The first is that it is a purposeful system and not a machine as thought of when the traditional project management approaches were defined and codified (Ackoff, 1974); the second is that it is part of one or more purposeful systems and the third is that parts of this system, people, have purposes of their own. This view indicates that organisations have societal, organisational and individual purposes and that how an organisation performs depends on how it is affected by the people it is staffed with and the systems which is part of (Ackoff, 1981). This means that Megaproject organisations need to deal with the unpredictability of internal and external stakeholders and use this to their advantage. (Brand, et al., 2019) identifies that there are three key concepts that are required to embrace Digital Business Agility. Recent experience in the United States of America (USA) and the United Kingdom (UK) suggests these same concepts enable successful digital innovation in a Megaproject environment. These concepts are:

- Design Thinking (Liedtka, 2018)
- Lean start-up (Ries, 2011)

- Agile at Scale (Rigby, et al., 2018)

There will be significant iterations among the concepts and there is a degree of overlap but the basic principle remains that a project needs to create an environment where big, audacious ideas can be generated, where they can be tested on a small scale and then iterated across the project. These techniques enable the organisation to embrace the unpredictability of the team members by fostering their creativity (Design Thinking), allowing them to experiment with new ideas (Lean Start-up) and implementing the ideas that deliver best value across the project by facilitating change (Agile at Scale). Simplistically this model can be thought of as a three-stage process, shown diagrammatically in Figure 2.

Think Big →Start Small →Learn Fast

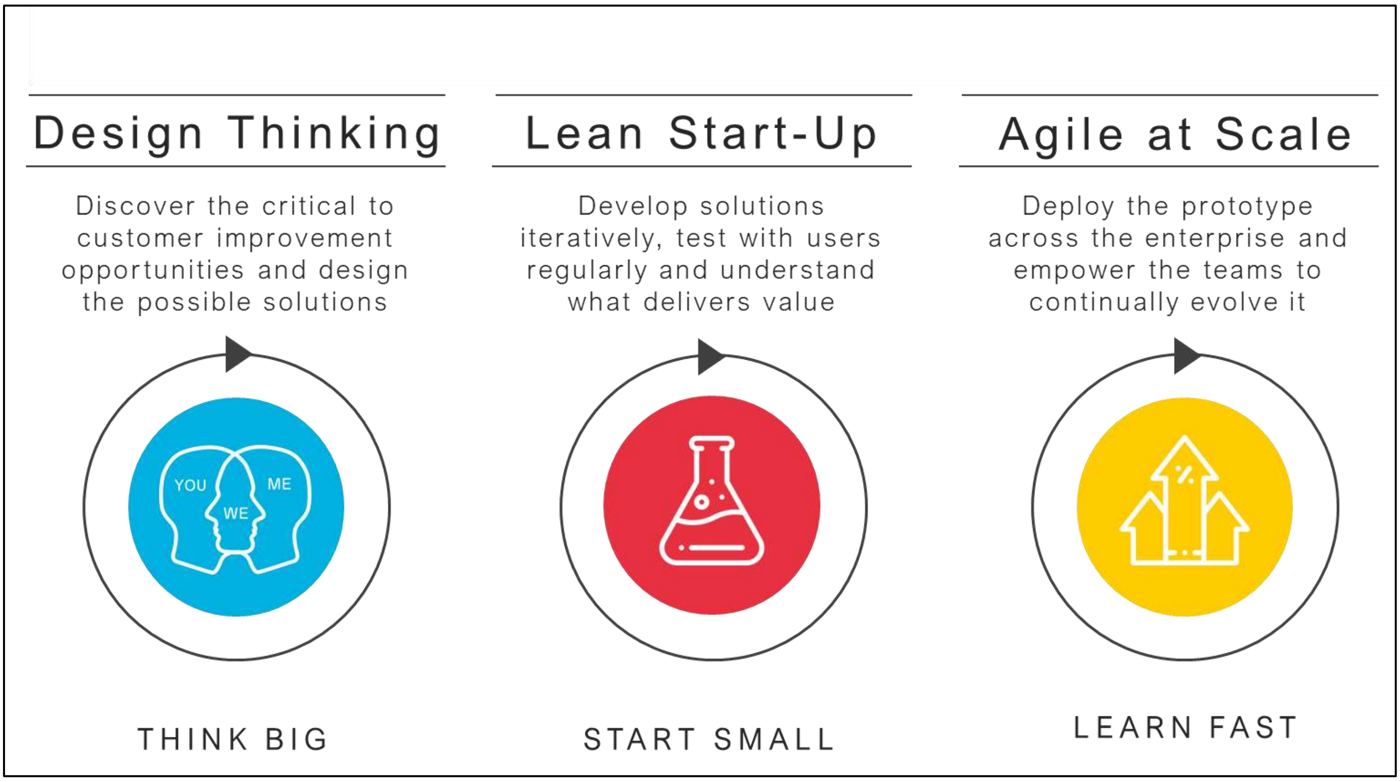

Figure 2 Design Thinking - Lean Start-up - Agile at Scale Model

The Digital Vortex suggests that all sectors will be pulled into the world of digital disruption and there is evidence that the infrastructure and transport sectors are starting to be disrupted (ICE, 2017). It is therefore important that Megaproject organisations should embrace the *Think Big →Start Small →Learn Fast* model and use it to guide them through this digital transformation. Coupled with alignment of Megaproject strategies to their existing capabilities (Lobo & Whyte, 2017) there is a growing need to identify the skills needed for Digital Business Agility.

COMPETENCES NEEDED FOR DIGITAL BUSINESS AGILITY

The operating model for highly agile, digitally enabled organisations adopting a *Think Big→Start Small→Learn Fast* mindset requires:

- Integrated (collaborative) working arrangements;
- Lean project delivery systems; and
- Agile product development and delivery.

Organisations need to be integrated, lean and agile if they are to survive the Digital Vortex and take advantage of the 4IR technologies and toolsets. This enables people to work in small teams, empowered to deliver, with automated oversight, taking rapid decisions and implementing change instantly. This is a very different environment from the classical model, with large, co-located project teams, working to highly governed processes, organised in siloed specialist work units, delivering an agreed scope to fixed budgets and timescales with little room to innovate or deal with enforced rapid change.

The project management approach required to operate at the centre of the Digital Vortex, using the *Think Big→Start Small→Learn Fast* approach can be thought of as turning the iron triangle upside down (Figure 3). The classical approach fixes the scope and defines a large set of requirements for every aspect of the project. These requirements are delivered by creating a complete set of activities for the whole project at the start, together with the resources required to deliver them. This results in a cost for the project which is assumed fixed at the beginning and often at a figure less than that calculated but much greater than the theoretical minimum. The objective of the project team is then to manage risk and change which is difficult to accommodate in the constrained timescales and often results in reduction of delivered scope, increase in cost or time or even all three things.

In the agile approach the cost and time is calculated by making a judgement of how much more cost than that required to deliver the theoretical minimum – the minimum viable product – should be spent to optimise the project's quality, safety, security and environmental requirements. This optimised cost and time is fixed for the project and the scope gradually evolves beyond the minimum viable product by incrementally adding features to a modular design solution until the planned cost and time is spent at which point operation can begin; as by definition, sufficient cost has been spent to justify the scope as being optimised (e.g. in a nuclear project this would be defined as the point at which the risk is "as low as reasonably practicable" - "ALARP").

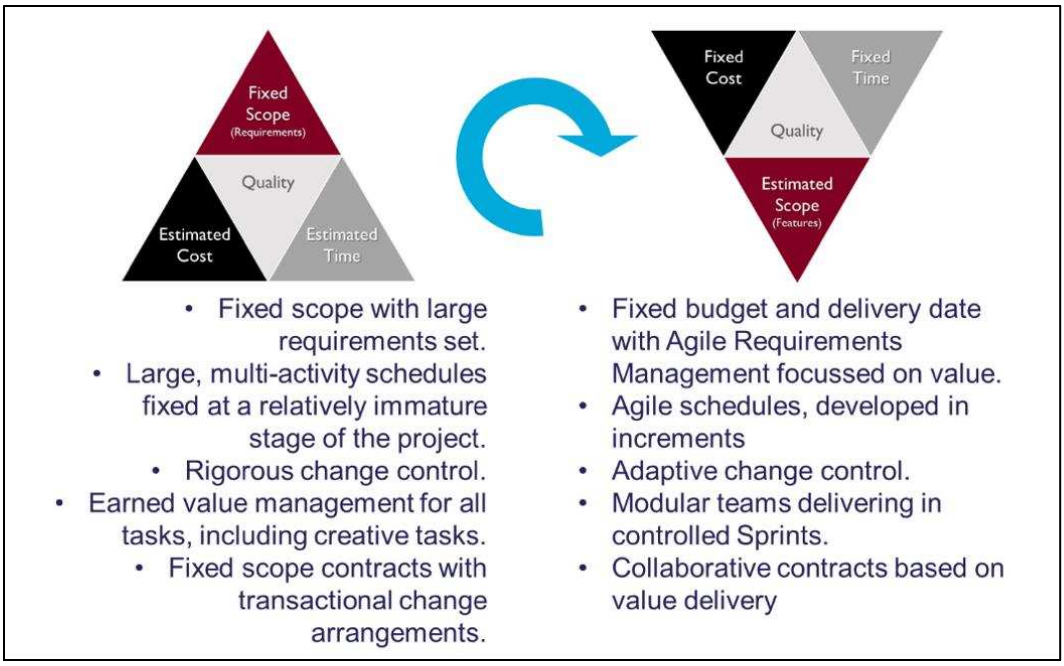

Figure 3 - Turning the iron triangle upside-down

In the following sections the proposed integrated-lean-agile model is developed in greater detail to highlight the competences required by project leaders and practitioners working successfully in a 4IR project delivery environment.

Integrated Working Arrangements

Communication among people and organisations working in projects and Megaprojects is always more complex, cumbersome, frustrating and ultimately more expensive than it should be in theory (Invernizzi, et al., 2018). Essentially, 4IR technologies enable collaboration among people and organisations (Papadonikolaki, 2016). To facilitate greater collaboration an enabling system (SEBoK-Editorial-Board, 2019) using shared data based on the product breakdown structure – e.g. a digital model, concurrent processes and collaborative behaviours is required. The key competences that enable the creation of this environment are systems thinking and relational leadership together with digital competence (and confidence) in implementing automated digital solutions. This enabling system, therefore, has people, process and digital components.

People: There is evidence that adopting partnering style contracts for complex projects promotes a stronger environment for the delivery of successful projects (Pryke, 2020).

> ***Charles Darwin:*** *"It is the long history of humankind that those who learned to collaborate most effectively have prevailed."* (Darwin, 1859)

The early nuclear industry put a strong focus on collaboration with some notable successes. At the time of Sizewell B, the latest nuclear reactor to be built in the UK, notably on time and on budget, John Collier the Chairman of Nuclear Electric said, "A good working relationship between client and contractors is crucially important – it has to be a partnership" (Collier, 1995). Research has shown (Johnston & Staughton, 2009) that there are seven *dimensions* that need to be managed to deliver successful Business-to-Business relationships. Most project managers focus on one of the dimensions, i.e. "interpersonal relationships". They have almost certainly never had any formal training in all seven, which include commercial, cultural and statistical issues. Many refuse to believe that soft issues (e.g. trust) can be measured and tracked which is one of the key conclusions of the Johnston and Staughton paper. This has been further confirmed in the infrastructure sector (Cerić, 2016). This leads to the first key competence:

> **Competence 1:** The creation and development of positive business-to-business relationships is a critical competence the project leadership must possess to release the collaborative benefits of 4IR technologies.

Process: Digital Business Agility recognises the *systems thinking* mantra that everything is connected to everything else with concurrent processes sharing common data.

> ***W Edwards Deming:*** *"Quality comes not from inspection, but from improvement of the production process."* (Deming, 1982)

In project terms this means the systems engineering activities must be interlocked to the project management activities to prevent the inherent lack of communication between the two separately designed processes. In the authors' experience, in some projects the "Systems Engineer's" Product Breakdown Structure (PBS) is not integrated with the "Project Manager's" Work Breakdown Structure (WBS); often the WBS is a mirror of the organisation with the main workstreams being organisational departments. The PBS should be embedded in the WBS and project managers should take ownership of the PBS elements. This then enables more process integration. This is further compounded by the fact that the ISO standards for Project Management (ISO 21500) and Systems Engineering (ISO 15288) have significant overlap which promotes poorly integrated processes.

Competence 2: In the 4IR-enabled project the project leaders and practitioners need to understand Systems Engineering and ensure the project and engineering enabling systems co-exist in a single concurrent process, sharing common data with no waste.

Tools: There is no point automating inefficient processes.

> ***Bill Gates:*** *"The first rule of any technology used in a business is that automation applied to an efficient operation will magnify the efficiency. The second is that automation applied to an inefficient operation will magnify the inefficiency."* (Gates, et al., 1995)

In the authors' experience, state of the art BIM systems have been used to print thousands of drawings to put in envelopes to send to vendors for checking. This is similar to the 'big BIM, little BIM' concept (Jernigan, 2008). There is some evidence that this may be a more acute issue in the UK where BIM has been institutionalised and where Government pressure to adopt BIM on all public sector projects results in a "box-ticking", compliance mentality. In a recent example a very large organisation familiar to the authors identified that one BIM-enabled project was producing over 10,000 unnecessary paper drawings and when this was corrected the flow rate through the design approval and checking process was significantly improved.

Digitalisation is never the answer to an inefficient process. Focussed process improvement action is the answer to an inefficient process and that has to be planned and executed before any automation takes place. The chosen processes for implementing digital tools to enable large infrastructure projects must therefore be lean and able to integrate with each other to enable processes to be automated and allow the people to focus on continuous improvement and innovation. The proliferation of digital solutions entails a number of proprietary and open-source systems that only partially support interoperability. Although open-source approaches are usually designed to support interoperability, typically large infrastructure projects strategically select proprietary and closed-source digital solutions that include training and customer support. In many ways it is better to choose legacy tools, because they tend to be more accessible to the users and have more third-party support. The demands of integration and collaboration require the project leaders and practitioners to be aware of and comfortable with, all the digital systems used on the project, not just the ones used by the project controls team. They need to be confident that they have been chosen for their ability to integrate not on their performance on isolated functions (organisational silos) of the project, e.g. design. The collaboration aspect is particularly important, as recent research suggests there is an increased dynamism in the way internal and external stakeholders engage and disengage throughout the project lifecycle (Pascale, et al., 2019). Thus, 4IR digital tools have an important role to play in such dynamic environments.

Competence 3: The project leaders and practitioners need to have an awareness of the architecture of the 4IR digital tools used by the entire project delivery team to the extent necessary to ensure the solution is integrated and enables automation of the overall project delivery process.

Lean Project Delivery Systems

Lean is based on removal of process waste and enhancing value until the overall process is optimised. In the 4IR this requires common data to be digitised, with concurrent processes which can then be digitalised. As teams digitise the data in their processes and automate the processes this frees them up to focus more on continuous improvement and innovation. Combined with the agile, small team approach they can become highly productive.

Using lean six sigma techniques to stimulate creativity and innovation the project manager can remove waste from the delivery processes and focus on value delivery. This requires a three-step process based on the Lean Start-up model: *Build-Measure-Learn* (Ries, 2011). The first step is to understand where the improvement opportunities are. Often the processes adopted for projects were developed for a different purpose; or even in a different industry. The earlier example showing that project management and systems engineering standards are not integrated emphasises this issue. This means project processes are loaded with activities that have no value for the specific project (i.e. waste) and may even be missing key value adding steps. The second step is to innovate to improve these processes (Think Big), then find a candidate area of the project to implement the solution (Start Small) and through clear metrics track the benefits of these improvements and feed the learning back into further improvements. This can be very empowering for the people involved. Generally, they know where the waste is and it can be highly motivating being given permission to hunt it down and remove it. The final step is to scale the improvements across the whole project organisation (Learn Fast) using the Scaled Agile Framework or the theory of the first follower (Sivers, 2010).

The result is a continuous improvement model that drives value and abhors waste; people are liberated rather than frustrated by their processes. The focal point of the lean six sigma approach is the "Work-Out"; a three-day innovation and improvement workshop, pioneered in General Electric (Ashkenas, 2015) and now used throughout industry. By focussing the Work-Out on innovation and creating an innovation environment the team can very quickly target areas for improvement and gain sanction to implement those improvements.

This approach is increasingly being used by the industry to improve project delivery processes. In the nuclear sector, a leading, large organisation has used lean techniques to increase the efficiency and effectiveness of its major project delivery processes. Over the course of 18 months they identified the critical pain points in their current processes and prioritised nine processes for improvement. They trained a number of Lean Champions to assist with the programme and monitored by a senior steering group they worked with the project teams to deliver measurable improvements in the candidate processes with identified project savings to-date of £94m.

Competence 4: The project leaders and practitioners need expertise in lean improvement techniques to ensure the procedures adopted for the project are efficient and effective. This needs to embrace all project procedures not just project controls.

Agile Product Development and Delivery

The final competence is agile product development in Megaprojects.

Project Leaders tend to use the same delivery approach for all large projects – based on a codified project management Body of Knowledge. However, it's not intuitive that you should use the same delivery approach for, say, the n^{th} iteration of a complex product like a gas turbine as you would for a one-off solution for a complex nuclear decommissioning project. The nature of the risks is very different on both projects. In one case the detailed requirements are well known upfront, whereas for the other the requirements are largely unknown and will need to be discovered as the project progresses.

In reality, the optimal approach for both types of project should be a *hybrid* of agile and classical (waterfall) techniques. This hybrid solution takes the learning from both approaches and fuses them into a bespoke system designed around the specific requirements of the venture. Using Agile at Scale (Rigby, et al., 2018) means that this can be applied to large projects as well as small ones. More than anything else the Hybrid approach enables an agile culture which responds quickly to change. Change is embraced as a key way of meeting the project objectives.

This Hybrid approach has been applied on a number of large engineering projects. (e.g. the SpaceX programme). Rather than a full Agile implementation, SpaceX developed what they call an interlocked model with some waterfall and some agile aspects (Mosher, et al., 2018). Some key learnings are starting to emerge from Hybrid implementation. Firstly, five key principles have been identified:

- **Focus on value**. Delivering value rather than inflexible contract deliverables is the goal. The decision-making focus is on what provides most value to society, i.e. Social Value.
- To produce a quality solution, a **modular design** is key. This enables features to be added throughout the design, construction and operational life cycle as they become available. More than anything else it is this concept which enables the time and cost to be fixed, by allowing the scope to float. The Waterfall features of the Hybrid governance model ensure the quality requirements are met in all iterations of the design.

- The organisation should be designed around the product's modules and not the organisation's functions. The fast pace of work and constant improvement of the solution by introduction of new features to modules requires **highly motivated and empowered small teams**.
- **Collaboration** must be enabled both by the culture of the organisation and by the processes and tools adopted. It is more important for the toolsets to be integrated than to use the latest state-of-the art-tool if it can't be integrated to the rest of the suite.
- A **regular cadence** for implementation of features should be adopted. This gives structure to the project and enables configuration control to be maintained at all times. This requires an agile-systems engineering concept called Agile Requirements Management which allows requirements to be discovered as the project progresses to maximise value.

The adoption of a modular design solution with relatively small teams working on these modules gives the people a high degree of ownership and autonomy to innovate, but the high-level value statements are clear and controlled and the innovation takes place in the discovery and development of the detailed requirements. Teams working in this type of environment find it highly motivating, stimulating and fast. If they are finding it impossible to make the current "feature" work there's always a new "increment" just around the corner where they can introduce a new modular feature into the solution. This also addresses one of the key stress- and pressure-inducing aspects of traditional projects; i.e. the difficulty of rescheduling to a realistic timeline once it becomes apparent the current scope can't be delivered in time or to cost.

The most complete implementation of an Agile approach on a large engineering project that the authors are aware of is SAAB and their fully agile delivery team for the Gripen E fighter programme (Furuhjelm, et al., 2017). More than 100 small teams, working in a highly empowered way, delivering flexible scope in short programme increments. SAAB claim some outstanding metrics for this project compared to its main competitor programme (the Lockheed-Martin F35 programme): The entire SAAB development team of 3,000 is about the same size as the PMO for the F35 programme; The SAAB development programme cost is €2bn compared to $50bn for the F35; 10 years development time vs. 16.

> **Competence 5:** The project leader and practitioners need to be Agile trained and the leaders need to be able to develop a bespoke Hybrid delivery model for the project which creates an empowered and highly motivated workforce able to pivot and deal with change in a rapid and effective way, to take advantage of innovation throughout the life-cycle.

CONCLUSIONS AND FURTHER RESEARCH

We are experiencing the so-called "projectification of society" (Gemünden, 2013). More and more resources (money, but also people's time, expertise etc.) are invested in planning and delivering projects. Projects and Megaprojects are not new; they have been delivered throughout human history, but there are at least two elements of novelty that have emerged in the last few years. Firstly, new classes of projects have emerged, for instance Megaprojects to deal with the decommissioning of infrastructure, e.g. the first generation of nuclear weapons and energy sites, and Megaprojects to deal with human made disasters, e.g. Chernobyl. This is a new evolution and there is a lack a body of experience to deal with them. Secondly, human aspects have much greater prominence in modern business policies. Today's focus on positive human behaviours such as diversity, inclusion, wellbeing, empowerment, collaboration and innovation are not adequately supported by traditional project management tools and techniques. A software-centred approach cannot fully support collaboration (Papadonikolaki, et al., 2019).

These tools and techniques, codified during earlier industrial revolutions, cannot deal adequately with these positive human aspects and cannot leverage the opportunities created by the 4IR. The Taylorism view of workers on which traditional project management techniques are based was to equate them to machines in a simple and repeatable process. The reality is that projects and Megaprojects are increasingly complex. This complexity is not just technical, e.g. the design of a nuclear reactor or a satellite, but also organisational, with multiple stakeholders with different cultures, needs, and goals and many systems that need to come together. The 4IR is and will be more so in the future a disruptive element. This disruption can be either positive (e.g. saving money, improving working conditions) or negative generating a further layer of complexity (e.g. different electronic, cyber security threats).

This paper has shown that the paradigm Think Big → Start Small → Learn Fast can release the positive benefits of 4IR systems in planning and delivering Megaprojects. To embrace this paradigm, five competences have been identified which are not generally part of a project professional's training:

- creation and development of positive business-to-business relationships
- understanding Systems Engineering to integrate project systems
- awareness of the architecture of the 4IR digital tools
- lean knowledge and competence
- understanding and applying Agile and Hybrid models

These competences are not just for the Project Leader but need to be disseminated and cultivated across the project team. They are essential in enabling the 4IR in successful Megaprojects. Success should no longer be measured as meeting requirements within some arbitrary budget and schedule. Success will be to plan and deliver Megaprojects that deliver social value to as many stakeholders as possible while empowering the people that deliver it. The project focusses on value not output, on collaboration between expert practitioners able to deliver their full contribution and not limited by restrictive contracts, on bespoke processes optimised for the specific project not boilerplate approaches derived from generic bodies of knowledge, enabled by systems chosen for their ability to integrate and not their feature list and finally and most importantly delivered by people released from fear of failure and who feel able to contribute their innovative ideas in a truly enabling environment.

Project studies to date advocate that successful performance depends on a front end that if done right will enable the project to do well in the future e.g. (Flyvbjerg, et al., 2009). Another view focuses on project execution, and advocates that good performance is dependent on developing new routines, practices and collaborations e.g. (Gill, 2009); (Tee, et al., 2019). Human aspects have traditionally been left behind as contributors to successful delivery of projects (Unterhitzenberger & Müller, 2020). Adding the digital dimension to the equation, can actually increase the burden and leave the project manager exposed, if he or she is not trained and equipped with the necessary skills and knowledge. Further research is needed to investigate the human aspect in projects and the interfaces between human behaviour, projects and how 4IR and Digital Business Agility might influence both. Future research could also investigate how 4IR and Digital Business Agility can re-shape project delivery models. There is evidence of how the first wave of new technologies have impacted project delivery e.g. (Davies & Mackenzie, 2014) and future research could investigate the long-term cost-benefit of 4IR tools and systems (e.g., will a BIM file be still accessible 20 years from now?).

In a world where constant disruption is the norm the project management community's response has to be to seek knowledge and new skills to help it to cope and take advantage of this disruption. The five competences identified in this paper facilitate this and help ensure megaprojects are ready for the 4th Industrial Revolution … and any other global disruption from whatever source.

References

Ackoff, R., 1981. On the Use of Models in Corporate Planning. *Strategic Management Journal,* Volume 2(4), pp. 353-359.

Ackoff, R. L., 1974. *Redesigning the future: a systems approach to societal problems.* New York: Wiley.

Ashkenas, R., 2015. Jack Welch's Approach to Breaking Down Silos Still Works. *Harvard Business Review,* Issue September.

Bradley, J. et al., 2015. Digital vortex: How digital disruption is redefining industries. *Global Center for Digital Business Transformation.*

Brand, S., Blosch, M. & Osmond, N., 2019. *Enterprise Architects Combine Design Thinking, Lean Startup and Agile to Drive Digital Innovation (ID: G00390198),* USA: Gartner, Inc..

Cerić, A., 2016. *Trust in Construction Projects.* London: Routledge.

Christensen, C., 2013. The innovator's dilemma: when new technologies cause great firms to fail. *Harvard Business Review.*

Collier, J., 1995. *Sizewell B from Concept to Completion; The 1995 Hinton Lecture.* London, Royal Academy of Engineering.

Cotteleer, M., Trouton, S. & Dobner, E., 2016. *3D opportunity and the digital thread Additive manufacturing ties it all together.* [Online] Available at: https://www2.deloitte.com/insights/us/en/focus/3d-opportunity/3d-printing

Darwin, C., 1859. *On The Origin of Species by Means of Natural Selection, or Preservation of Favoured Races in the Struggle for Life..* 1 ed. London: John Murray.

Davies, A. & Mackenzie, I., 2014. Project complexity and systems integration: Constructing the London 2012 Olympics and Paralympics Games. *International Journal of Project Management,* 32(5), pp. 773-790.

Deming, W. E., 1982. *Out of the Crisis.* 2 ed. Boston: The MIT Press.

Fayol, H., 1916. *Administration industrielle et générale.* Paris: Dunod.

Flyvbjerg, B., 2018. Five things you should know about cost overrun. *Transportation Research Part A: Policy and Practice.*

Flyvbjerg, B., 2019. On de-bunking “Fake News” in the post-truth era: How to reduce statistical error in research. *Transportation Research Part A: Policy and Practice.*

Flyvbjerg, B., Garbuio, M. & Lovallo, D., 2009. Delusion and deception in large infrastructure projects: Two models for explaining and preventing executive disaster.. *California Management Review,* 51(2), pp. 170-193.

Furuhjelm, J., Segertoft, J., Justice, J. & Sutherland, J. J., 2017. Owning the Sky with Agile, Building a Jet Fighter Faster, Cheaper, Better with Scrum.

Gantt, H., 1919. *Organizing for Work.* New York: Harcourt, Brace and Howe.

Gartner, 2013. *Gartner IT glossary: Technology Research,* Stamford: Gartner.

Gates, B., Myhrvold, N. & Rinearson, P., 1995. *The Road Ahead.* 1 ed. New York: Viking.

Gemünden, H. G., 2013. Projectification of Society. *Project Management Journal,* Volume 44(3), p. 2–4.

Giezen, M., 2012. Keeping it simple? A case study into the advantages and disadvantages of reducing complexity in mega project planning. *International Journal of Project Management,* Volume 30(7), p. 781–790.

Gill, M. a. V. S., 2016. The digital maturity model 4.0. *Benchmarks: Digital Transformation Playbook.*

Gill, N., 2009. Developing project client-supplier cooperative relationships: How much to expect from relational contracts?. *California Management Review,* 51(2), pp. 144-169.

Greco, M. L. G. &. L. S., 2017. Open innovation in the power & energy sector: Bringing together government policies, companies’ interests, and academic essence. *Energy Policy,* Volume 104, pp. 316-324.

Henderson, R. &. C. K., 1990. Architectural innovation: The reconfiguration of existing. *Administrative science quarterly,* Volume 35, pp. 9-30.

ICE, 2017. *State of The Nation 2017: Digital Transformation. P.2.,* London, UK: Institution of Civil Engineers.

Invernizzi, D. C., Locatelli, G. & Brookes, N. J., 2018. The need to improve communication about scope changes: frustration as an indicator of operational inefficiencies. *Production Planning & Control,* Volume 29(9), pp. 729-742.

Jernigan, F., 2008. *Big BIM, little bim: the practical approach to building information modeling: integrated practice done the right way!.* Jacksonville: 4site Press.

Johnston, R. & Staughton, R., 2009. Establishing and developing strategic relationships – the Role for Operations Managers. *International Journal of Operations and Production Management,* Volume 29(6, pp. 564-590.

Krystallis, I., Demian, P. & Price, A. D., 2015. Using BIM to integrate and achieve holistic future-proofing objectives in healthcare projects. *Construction Management and Economics,* Volume 33(11-12), pp. 890-906.

Liedtka, J., 2018. Why Design Thinking Works. *Harvard Buisness Review.*

Lobo, S. & Whyte, J., 2017. Aligning and Reconciling: Building project capabilities for digital delivery. *Research policy,* Volume 46(1), pp. 93-107.

Locatelli, G., 2013. Improving Projects Performance With Lean Construction: State Of The Art, Applicability And Impacts. *Organization, Technology and Management in Construction: An International Journal,* Volume 5(2), p. 775–783.

Locatelli, G., 2018. Why are Megaprojects, Including Nuclear Power Plants, Delivered Overbudget and Late? Reasons and Remedies. *MIT-ANP-TR-172.*

Locatelli, G., Invernizzi, D. C. & Brookes, N. J., 2017. Project characteristics and performance in Europe: an empirical analysis for large transport infrastructure projects. *Transportation Research Part A: Policy and Practice,* Volume 98, p. 108–122.

Locatelli, G., Mancini, M. & Romano, E., 2014. Systems Engineering to improve the governance in complex project environment. *International Journal of Project Management,* Volume 32(8), p. 1395–1410.

Love, P. E., Ika, L. A. & Ahiaga-Dagbui, D. D., 2019. On de-bunking “fake news” in a post truth era: Why does the Planning Fallacy explanation for cost overruns fall short?’,. *Transportation Research Part A: Policy and Practice.*

Manners-Bell, J. & Lyon, K., 2019. *The Logistics and Supply Chain Innovation Handbook: Disruptive Technologies and New Business Models,* s.l.: Kogan Page Publishers.

Merrow, E. W., 2011. *Industrial Megaprojects: Concepts, Strategies and Practices for Success.* Hoboken, NJ: John Wiley & Sons.

Mosher, T. J., Kolozs, J. & Wilder, E., 2018. *Agile Hardware Development Approaches Applied to Space Hardware.* Orlando, AIAA SPACE and Astronautics Forum and Exposition (p. 5233).

Papadonikolaki, E., 2016. *Alignment of Partnering with Construction IT: Exploration and Synthesis of network strategies to integrate BIM-enabled Supply Chains,* Delft: Delft University of Technology.

Papadonikolaki, E., 2020. The Digital Supply Chain: Mobilising Supply Chain Management Philosophy to Reconceptualise Digital Technologies and Building Information Modelling (BIM). *Successful Construction Supply Chain Management: Concepts and Case Studies.*

Papadonikolaki, E., Olel, C. v. & Kagioglou, M., 2019. Organising and Managing boundaries: A structurational view of collaboration with Building Information Modelling (BIM). *International Journal of Project Management,* 37(3), pp. 378-394.

Parast, M. M., 2011. The effect of Six Sigma projects on innovation and firm performance. *International Journal of Project Management,* Volume 29.1 , pp. 45-55.

Pascale, F., Pantzartzis, E., Krystallis, I. & Price, A. D., 2019. Rationales and practices for dynamic stakeholder engagement and disengagement. Evidence from dementia-friendly health and social care environments. *Construction Management and Economics,* pp. 1-17.

Pryke, S., 2020. *Successful Construction Supply Chain Management: Concepts and Case Studies.* Hoboken, NJ: John Wiley & Sons.

Ries, E., 2011. *The lean startup, P.27.* New York: Crown Business.

Rigby, D. K., Sutherland, J. & Noble, A., 2018. Agile at Scale. *Harvard Business Review,* Issue May-Jun.

Ross, J., 2017. Don’t confuse digital with digitization. *MIT Sloan Management Review.*

Schwab, K., 2017. *The fourth industrial revolution.* New York: Currency.

SEBoK-Editorial-Board, 2019. *The Guide to the Systems Engineering Body of Knowledge (SEBoK), v. 2.1.* [Online] Available at: www.sebokwiki.org

Serrador, P. & Pinto, J. K., 2015. Does Agile work? - A quantitative analysis of agile project success. *International Journal of Project Management,* Volume 33(5), p. 1040–1051.

Sivers, D., 2010. *Derek Sivers: How to Start a Movement,* s.l.: TED.

Taylor, F., 1911. *The principles of scientific management.* New York: Harper and Brothers.

Tee, R., Davies, A. & Whyte, J., 2019. Modular designs and integrating practices: Managing collaboration through coordination and cooperation.. *Research Policy,* 48(1), pp. 51-61.

Unterhitzenberger, C. & Müller, R., 2020. Special issue on Project Behavior.. *Project Management Journal.*

Wade, M., Shan, J. & Noronha, A., 2017. *Life in the digital vortex,* s.l.: Global Center for Digital Business Transformation.

Westerman, G. et al., 2012. *The Digital Advantage: How digital leaders outperform their peers in every industry,* Boston: MIT Sloan Management and Capgemini Consulting.

Whyte, J., 2019. How Digital Information Transforms Project Delivery Models. *Project Management Journal,* Volume 50(2), p. 177–194.