Built Environment 2050

A Report on Our Digital Future

BIM2050

Construction Industry Council

Foreword

The age of digital is upon us; it is part of everyday life and is reforming industries across the globe. As our built environment shifts away from Victorian processes, we need to challenge preconceived ideas, set a compelling vision for our industry and build pathways towards a sector where digital and physical interact.

The industrial strategy for construction, Construction:2025, sets out the vision of a smart industry that is efficient and technologically advanced. With a tidal shift in how we are creating and caring for our assets, it is essential that we build solid digital foundations where we can unlock the prize of a global construction market forecast to grow by over 70% by 2025.

This report by the BIM2050 Group illustrates the need for organisations to consider new skills, new processes and develop strategies around emerging technologies that will ensure that the UK stays at the vanguard of construction in a digital future.

Peter Hansford,
Government Chief Construction Adviser,
September 2014

The BIM2050 group comprises 18 young construction professionals from all areas of the industry. The group was formed in September 2012 by the Construction Industry Council (CIC) to work in partnership with the HM Government UK BIM Task Group in developing a range of government initiatives, which have included the BIM regional hubs and the specialist BIM4 groups, to ensure industry-wide awareness of BIM, in preparation for implementation of the government's mandate for BIM Level 2 on all publicly funded building and infrastructure projects by 2016.

As its name suggests, the group's vision looks ahead to the construction industry of the future. These young professionals, under the Chairmanship of David Philp, of the HM Government UK BIM Task Group, have been tasked with positively shaping that future by researching and reporting on what an interdisciplinary scope of work may look like as construction technology develops to BIM Level 3 and beyond, towards 2050.

The report comprises a compilation of essays authored by BIM2050 work stream leads, and focuses on three key areas - education and skills, technology and process and the culture of integration. It highlights the risks and challenges, and the opportunities and benefits that come with large scale innovation and game-changing new technologies. It is an important discussion document of ideas and concepts that will, I hope, spark debate in the wider construction community.

Graham Watts OBE,
CIC Chief Executive,
September 2014

Acknowledgements

BIM2050 Team

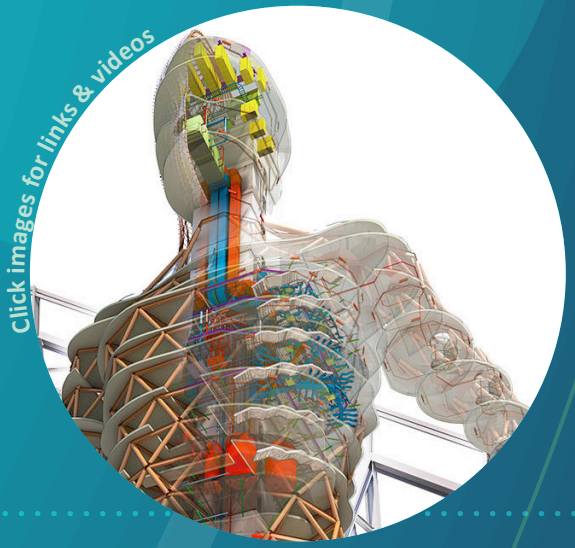
Chair: David Philp, FRICS, FCIOB FGBC, BIM Task Group & Mace Group
Lead Author: Neil Thompson, CIBSE- Balfour Beatty
Lead: Rebecca De Cicco, RIBA - Digital Node
Lead: Rebecca Hodgson Jones, MICE - Sir Robert McAlpine Ltd
E&S Lead: Rachael Atkinson, RICS - MACE
T&P Lead: Chris Barker, CIOB - Wates Construction
CoI Lead: Wes Beaumont , MCIOB - Turner & Townsend
PM: Ian Aldous, MRICS - EC Harris LLP
Legal: Khalid Ramzan - Pinsent Masons
Comms: Stefan Mordue, RIBA, APM, APS - RIBA Enterprises

Organisations

Construction Industry Council - Andew Link
BIM Task Group - Mark Bew & Jamie Johnson
University College London - Tim Broyd
Class of Your Own - Alison Watson
Soluis - Martin McDonnell
Topcon - Ian Stilgoe
The B1M - Fred Mills
Arup & Arup Associates- Casey Rutland
Project_Ove - Andrew Duncan

Contents

"Seeking to develop a culture which enables a digitally integrated approach to positively impact our built environment."



Executive Summary

The future of our industry is facing a high degree of complexity, extreme competition and uncertainty with respect to the outcomes of climate change, availability of resources and the disruptive nature of innovation. Regardless of their origin, these factors will indirectly stimulate a rate of change in our sector, which will have a direct impact on every aspect of the built environment as we know it.

The UK's heritage in construction is a centre of excellence, using our skills in design, engineering and manufacturing have produced some of the best examples of social and economic infrastructure globally. As we continue to export our knowledge and products, we must be more integrative in our approach to other sectors and academic disciplines. The UK also leads in biomedical and social sciences. As our industry integrates the development of material sciences we must also take advantage of the developments in psychology and behavioural economics.

The 'hard skills', such as engineering will remain a core activity of construction but it appears that the sector's inefficiency manifests from a lack of soft skills and poor cultural integration of education and skills, such as interdisciplinary teams and emotional intelligence. The premise Building Information Modelling becomes unimportant in the light of the change needed to effectively deploy true value adding processes and technology. We urge the construction industry to consider the following in their respective organisations:

Will your organisation secure against cyber-attack? *Digitally connected infrastructure and business systems are vulnerable to electronic terrorism and sabotage. Just because your information is secure now it does not mean it will be secure in the near future.*

Are you thinking about integrated infrastructure? *Ambient intelligence and smart cities can only be constructed if technology is interoperable. The specification of products will become critical and opportunistic substitutions (swapping for cheaper and poorer quality intentionally) will be detrimental to the end users of smart cities.*

Are you constructing the right teams? *Behavioural intelligence management will set the foundations of the demountable organisations already seen in mega-projects. This will impact the business practices of top to middle range supply chain members.*

What impact will nano-second procurement have on commercial practice? *Procurement will become almost instantaneous and will shift the paradigm of procuring construction projects. Mobile capital will also impact the way we transact with the construction supply chain.*

How will you support Life-long learning? *As construction becomes less labour intensive, the skill base will need to be agile and feature strong links to academia as the nature of working in construction becomes precise, and the level of definition required to deliver self assembled projects is down to the molecular level.*

What will be the impact of consumer access on your supply chain? *Rental markets for consumer access have already emerged but the idiosyncrasies of space tourism will accelerate innovation in construction and autonomous vehicles will open a market for production and consumption on the go. Building out of gravity and on other planets will transfer innovation to terrestrial construction techniques, such as additive manufacturing using in situ materials.*

Are you ready to manage sector skill migration? *Globalisation has enabled cultures to blend, so too will skills between sectors. The mobility of skills in sectors and geographies will be supported by smart cities, integrated infrastructure, nano-second procurement and mobile capital.*

What will your inventory of equipment look like when systems are autonomous? *It would look much like the rental service based market for consumers. Robotic and autonomous systems will enable service models for lower tier supply chain members and specialist contractors, fundamentally changing the labour market in construction.*

How do you currently manage human capital? *Talent will soon be a fierce battleground for organisations and as clients currently assess the behaviours of their supply chains, larger tier 1 supply chain members will need to address their business models and management of human resources.*

The aim of this report is to provide a framework to question what these developments mean for your organisations and careers. We want to spark debate amongst the industry and welcome challenges to our research.

Introduction

"The construction industry contributes almost £90bn to the UK economy (6.7% of the total) and its value comprises of 280,000 firms employing 2.93 million people, most of that employment is skilled labour. What will happen when we only need half of that labour?"

Professor David Philp – BIM2050 Group Chair

What do you envision the construction industry will be like come 2050, against the backdrop of a digitised built environment? This was the challenge set to the BIM2050 Group, an initiative formed via the Construction Industry Council, and made up of eighteen early professionals representing eleven institutes.

The group launched their mission to a full-house on the 16 of January 2013 at the Building Centre in London and announced that they were "seeking to develop a culture which enables a digitally integrated approach to positively impact our built environment".

The group is also a vehicle to pass the baton of digital reform to the next generation of young construction professionals, providing them with a voice to challenge existing ways of working and to deliver better results for the public and UK plc.

A starting point for the group was contributing to the Industrial Strategy for Construction: 2025, and the report announced that we are going to be "an industry that is efficient and technologically advanced". Mark Bew, Chair of the BIM Task Group notes that "construction is the last bastion of the analogue world"; the group saw the Level 2 BIM programme as a key enabling strategy, not only as a good basis from which to start, but also to look towards Level 3, and beyond.

We want to challenge those reading this report to be intentionally disruptive; to help them see what a digitally integrated future could look like; to enable them to shape the opportunity and avoid the risks of doing nothing. Ultimately, it is hoped that it could become a framework for industry to create a pathway to future, more desirable outcomes. Hopefully we might even create a new innovative industry, whilst turning the traditional social image of construction on its head!

Future gazing is notoriously difficult, however there are trends emerging that we can use to help predict change over the next couple of decades. The construction sector is undergoing a tremendous technology-led revolution, and is moving towards the world of digital transactions and queries. This transformation of the construction industry to a digital and innovation based sector will have profound changes, as explored in this report.

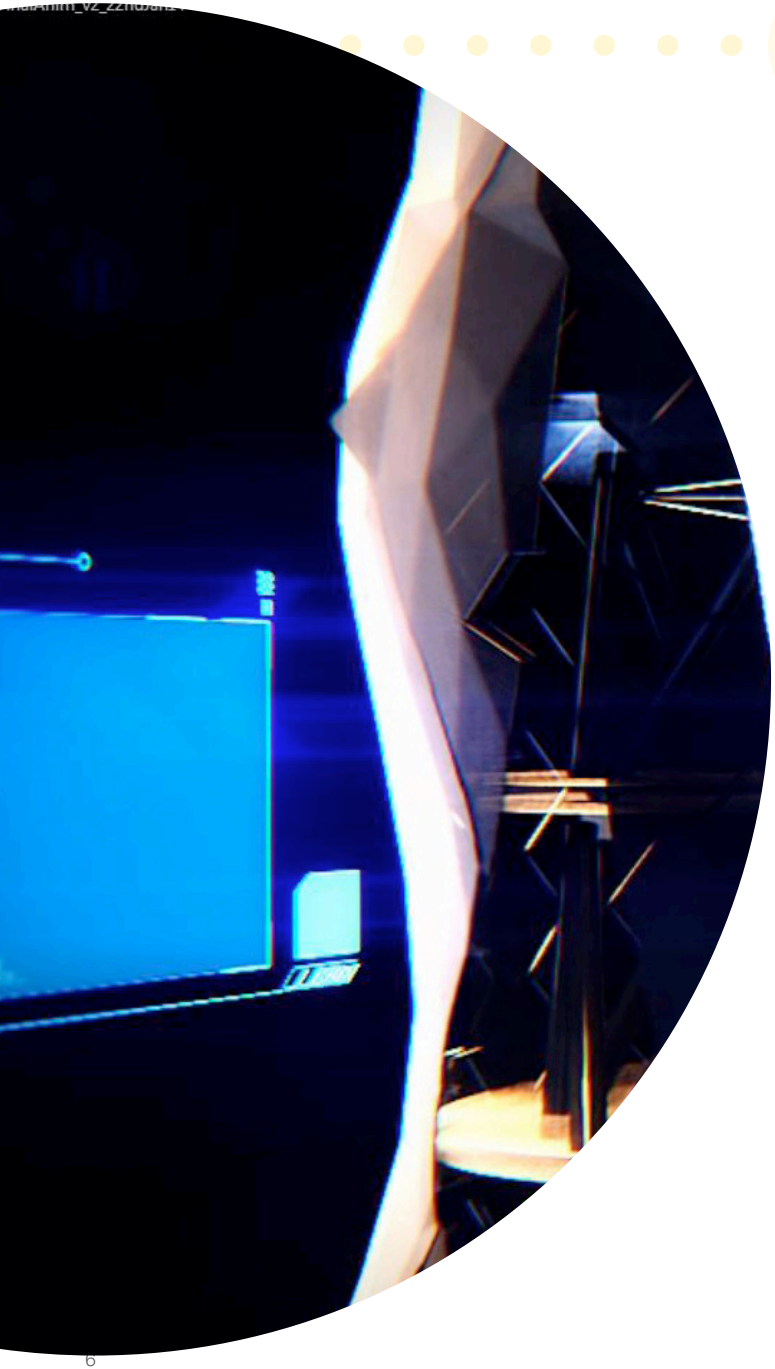
"Economists have estimated that the UK market for BIM-related services will be an annual £30bn by 2020 in a global context"

Organisations will need to adapt quickly to radical changes, and must question if they are moving quickly enough to make the necessary adaptations, which are often complex.

There will be an ever growing need to manage our future digital construction sector more effectively. We also need to assess what these technology-based interventions will mean to process; and the impact on the construction professions, especially the next workforce, generation Y.

Despite a mild dose of culture shock, the prognosis for data-led construction, based upon the Level 2 programme, is shaping up to be a very healthy one. We hope you enjoy the report and that it will help you discover a future vision of the built environment and a basis to create a sound strategy to help get you there.

If we aim for a performance based predictive data industry based on telemetry and social interactions – our future digital built environment will have unbounded potential.



Background

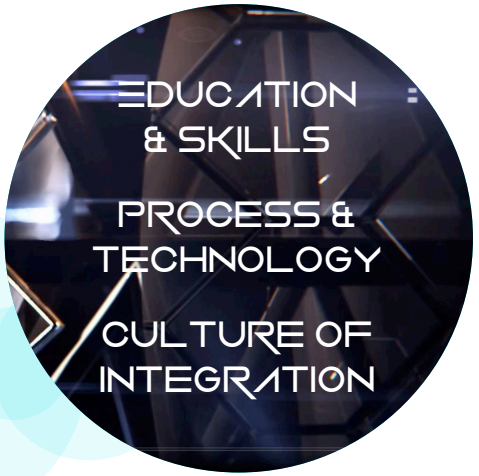
It was against this backdrop that the BIM2050 Group was launched, with the aim of enabling early construction industry professionals to make a contribution to the pressing issues of today. Their ambition is to lead an industry that is fit for purpose in a fast paced, digital and technologically advanced global economy. The group is hungry for changes in cultural collaboration, and aims to set itself apart from the current construction industry climate and focus its research outside of the sector, to see what is in store post-2016 and leading towards 2050.

Over the last 20 months the group's main focus has been to drive an open approach to collaboration and technology, while remaining informed and aligned to the key individuals and industry bodies, which are linked to the Government's objective of achieving Level 2 BIM, on all centrally procured projects, by 2016.

One of the group's main drivers is to ensure that we promote construction as the industry of choice for future talent. Therefore it is crucial we remain active at industry events and closely connected to those leading these processes. We have attended both national and international events to ensure this message is heard.

The group's ambition is for an industry which positively embraces technology and the potential of data transaction, in order to help improve performance of our assets and meet client expectations. We want to build on the work of the BIM Task Group and develop it further, looking into the future to 2025 and onwards to 2050.

We have categorised the industry and its operation into three work-streams:



The aim was to focus on these three areas to achieve the outcomes identified above.

Initially we needed to understand where the industry stood in this context. We began by researching where the lack of knowledge or innovation existed, and established that an awareness of potential future impacts was quite dispersed. This led us to focus on particular groups and associations. In 2013 we were involved in a series of events connected to Higher Education including UCL and MIT and we had close ties to the BIM Academic Forum. This linked back into some of the work we were doing downstream into junior and secondary schools.

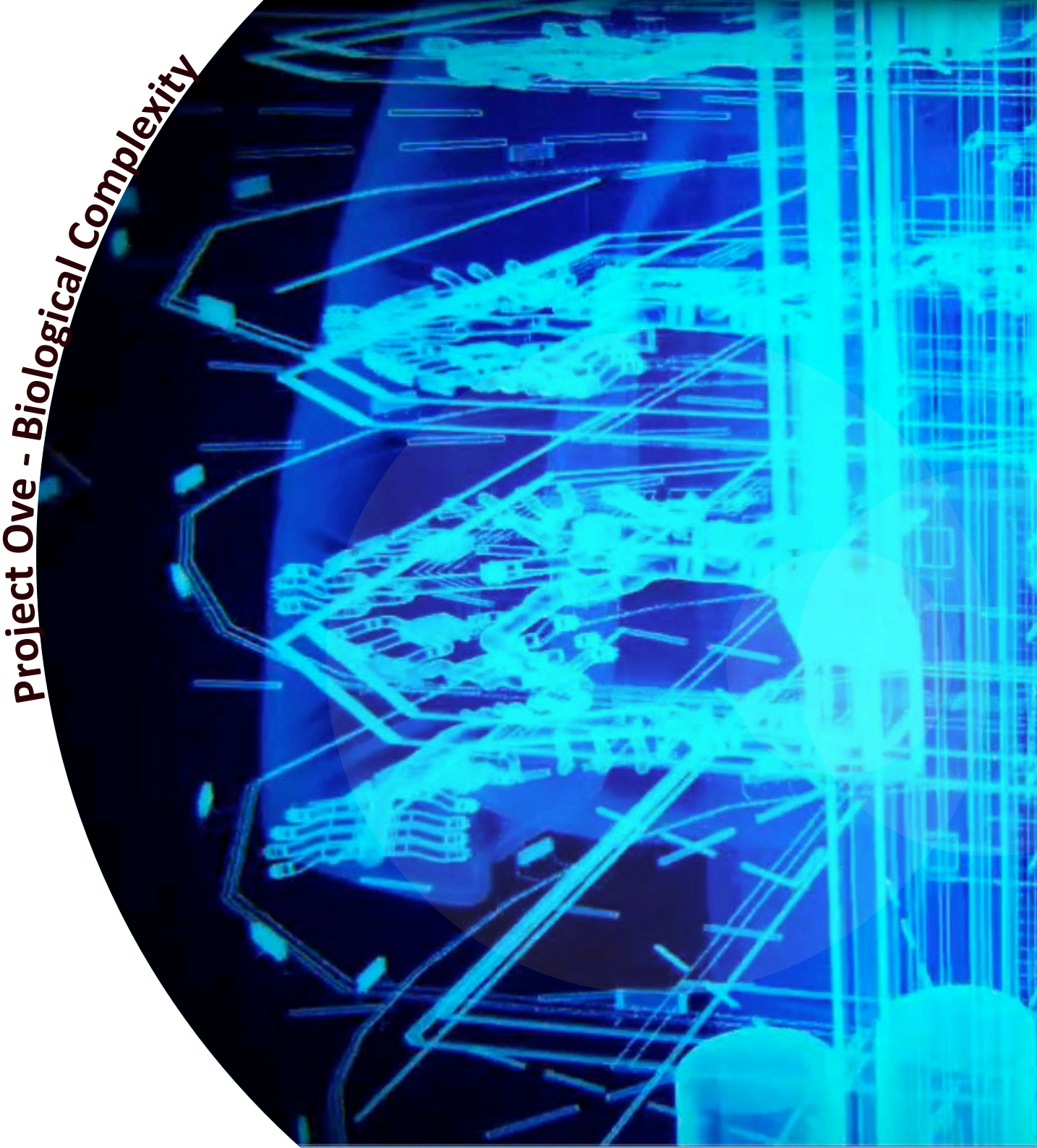
We also ensured that we linked back to the current Task Group leads, for example by interactive sessions with Government officials and the Ministry of Justice Trial Project team. Understanding the current Level 2 challenges and processes allowed the team to research areas such as engineering, molecular biology, architecture, law and economics and, explore if there were any parallels with the Government Industrial Strategy, released in July 2013.

We hosted a symposium in September 2013, which included a selection of key industry leaders, from both construction and other industries, to provide feedback to a series of key questions that were put to the audience. The findings and content of this symposium are key to developing the recommendations laid out in this report.

2013 concluded by exploring export opportunities with a series of non-UK events with education and technology at the forefront. With this information we explored future context and understanding, in a changing industry and an ever more uncertain world.

"Technology has outpaced our ability to educate generally across the economy and will continue to do so moving forward. Construction tends to lag behind more advanced industries and investment in innovation is low, both academically and professionally. How will the needs of an advanced industry adapt to these ever increasing changes?"

Rebecca De Cicco – Steering Group Lead



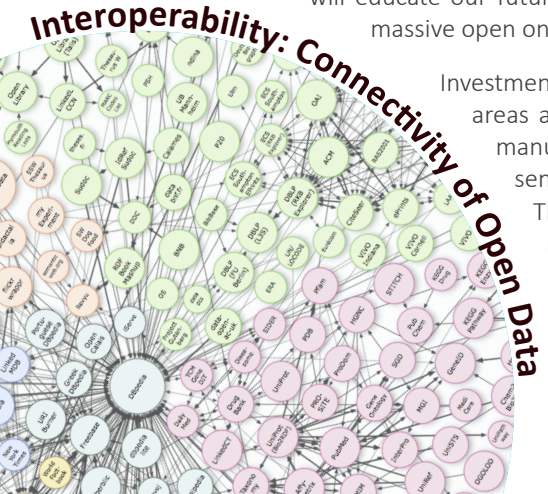
Our Socio-technological Frontier

"Our behavioural biases in construction inhibit collaboration. We need to change the stereotypical relationships between disciplines. Future generations will not accept these conventions and construction will remain a second choice career route for talented people. How can we address our image and make construction attractive to talented people?"

Neil Thompson – Group Vice Chair

The group's vision of the future integrates both technological and digital advancement, filtered through the sociological impacts of our industry, such as employment and wellbeing of labour. We extended research into many sectors, from the future of robotics in medical sciences through to the developments in the technology that will educate our future generations, such as massive open online courses.

Investment is required in such areas as IT infrastructure and manufacturing to embed sensor technologies. This, in turn, will require research and development around interfaces and associated protocols that surround future consumer goods and services. Interoperability between hardware, including sensors and numerous integrated datasets will become increasingly important as we move away from managing our individual assets, to the development of smart cities, smart grids and ultimately a global inter-connected network or 'internet of things'.



Additive manufacturing, for example 3D printing, needs further development in terms of up-skilling and multiple component printing; especially filament heads that can print digital circuitry. This will require general education to include appropriate design practices and processes at the core, described in our STEAME framework in the Education & Skills section of this report.

Clients will introduce self-procurement, which makes use of a standard kit of digital parts (a digital version of Lego), and integrated real-time data sets, an example of this is the real-time data from public transport that powers the apps on our devices today. As the integration of rule-based design processes increases, nano-second procurement will become possible (transacting in real-time). It will be supported by automated regulatory checking, enabling the faster delivery by 50% as envisaged by the construction:2025 Strategy. This will require incumbent supply chains to think about their business models.

This leads to a paradigm shift in commercial environments where new forms of contract and insurance will be needed in response to an integrated horizontal and vertical business models and supply chains that transacts in real-time. An example of this is the stock market where prices are set almost instantaneously, adjusting to events and market conditions as they happen.

Carbon costing will become a critical factor of asset life-cycle procurement. As the global population plateaus (UN, World Population to 2300) the need for new assets diminishes and leads to a 'non-additive construction cycle'. Gross fixed capital formation (an economic measure of construction output) will continue to grow in developing countries, while the net present value calculation and other investment decision methods in developed economies will favour non-additive construction projects (renovation and retrofit). This means that new build construction in developed countries will continue to slow down whilst in developing countries will still experience a level of growth, they will need to employ sustainable building techniques and learn from the developed economies.

The cost of carbon and raw materials will cause unsustainable inflationary effects on construction material prices. Ultimately this will divert resources into a circular economy and minimise the level of 'environmentally heavy' raw materials used in construction.

As modularised construction and ICT intensifies, the need for skilled labour will reduce by approximately 50%. This is in line with the Government's strategy for 2025 and is based on 2004-2013 UK Construction employment data (ONS 2013). Conversely, there will be a rise in information management and computational design roles.

Moore's Law, as a function of the rate of change of processing power, could end as new computer processing technology, such as quantum computing, sees a new dawn in computing power. Self-assembly results from the study of biological processes behind protein synthesis and scaling it up to a human level. Although in the early stages of research, 2030 should see the emergence of the results of early adoption programmes and 1:1 scale applications. This development will enable materials to be programmed to 'self build' and will challenge the legal and institutional framework of construction.

Not all projections into the future are positive. At the time

of release, a computer cluster is able to cycle through as many as 350 billion password guesses per second. Passwords have never been weaker, and hackers have never been more powerful. Passwords are not the only line of defence for confidential information online, but we have always been told that passwords are the answer- as long as they are sophisticated. Today we are at a stage where our passwords must be impossible to remember. What does this mean for our digitally-processed simulated and managed assets?

Another example is how independently-anonymised data sets are combined to reverse-engineer the anonymisation process. This will compound the current trend for data entry by users, who will either completely avoid the entry of their information, or use false details. This is a problem for data mining which requires a sufficient level of accurate data to be of value to anyone. Arvind Narayanan, a post-doctorate fellow at Stanford University studied the anonymised data of the online movie rental service Netflix. The study concluded that it was possible to reverse the anonymisation and process the data in order to identify the political views and sexual orientation of individuals. This was from a relatively simple entertainment rental service, imagine the political impact on mining social and economic infrastructure information!?

Additive manufacturing techniques are redefining the supply chains of other sectors and how products are procured and delivered. As these manufacturing techniques become mature and traditional logistical paradigms break down, it is likely that skill and sector migration will occur. Migration meaning both geographical and sectoral. This is a direct effect of globalisation, which has already seen the homogenisation of culture; and boundaries of sectors must follow.

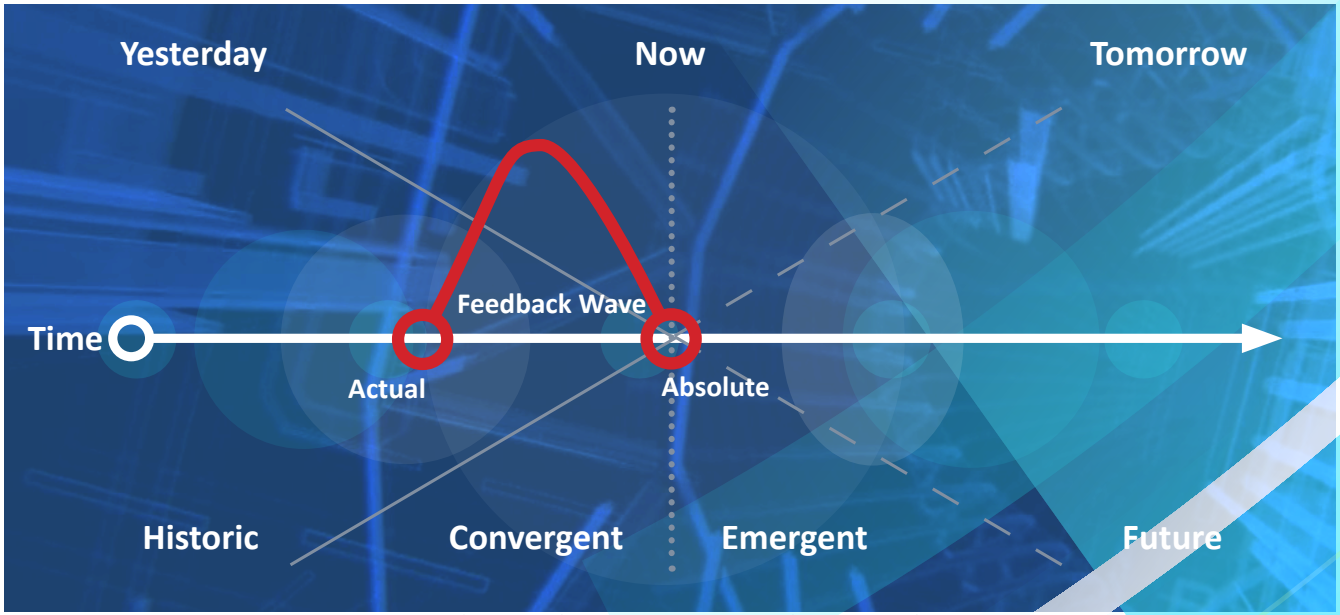


Figure 1 Based on: Time horizons, convergent and emergent, Thompson 2014, UCL

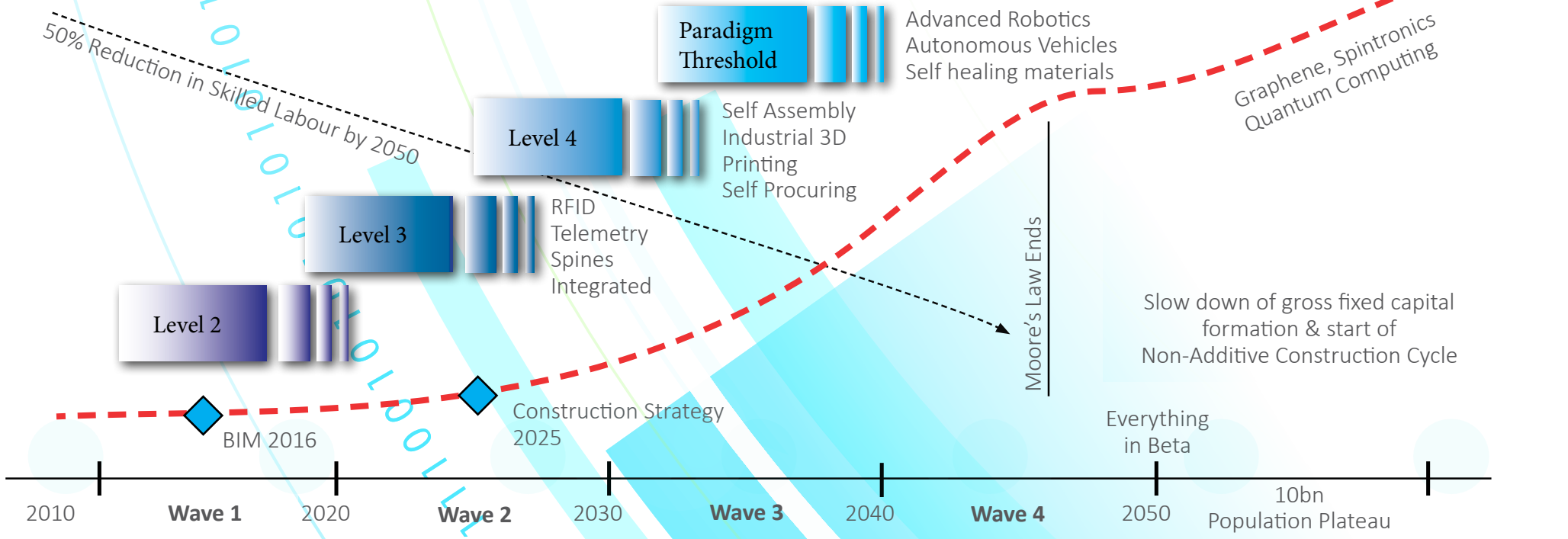
Moving from an analogue world to a world where decisions are driven through emergent information (via computational support), it is important to keep in mind that a human interface is always required for sense making of data and final accountability in contracts. Our model is based on moving the information time horizon as close to the emergent information line as possible (the middle of the diagram below).

Information lag, or feedback cycles using current technology and processes, mean that transactions are based on laborious convergent information; and the difference between the absolute information required to make an effective decision (the centre of the diagram) and the actual information available (a point further to the left) is a margin of error and relative exposure to risk. This constitutes incomplete and asymmetric information for both the employee and employer. The magnitude of the feedback cycle lag is shown by the feedback cycle wave overleaf.

We base our decisions on historic information, and information is not instantaneous, its 'sticky'. This means we are deciding our choices now with information that is actually out of date. This is one of the reasons why construction is risky and in most cases, requires large organisations to manage risk and uncertainty.

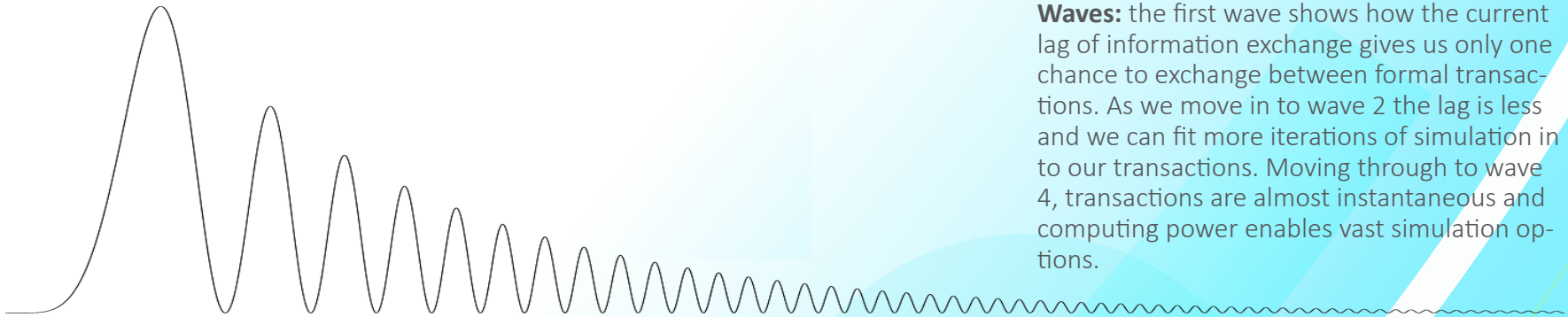
Imagine if we reduced that lag to a point where we only deal with converging and emerging information? Our project controls can be computational (simulate to a higher degree of accuracy) and be more proactive. We could spend our resources in designing better outcomes for clients and end users. Construction information can become consumable by public services such as, crime prevention, fire fighting and healthcare. Figure 1 only looks at a single transaction, the feedback cycle looks at the aggregate of transactions and proposes that they will develop in waves.

Socio-technological Frontier



Level up: Key technologies have been placed in the context of the levels of BIM maturity across a timeline. This has been mapped against other factors such as skilled labour and Moore's Law. Everything in Beta refers to the agile management of the future state of transactions, technology implementation and construction.

Feedback Cycle Wave: ©Philp, Thompson 2013



Waves: the first wave shows how the current lag of information exchange gives us only one chance to exchange between formal transactions. As we move in to wave 2 the lag is less and we can fit more iterations of simulation in to our transactions. Moving through to wave 4, transactions are almost instantaneous and computing power enables vast simulation options.

Feedback Cycle Wave

Wave 1	Wave 2	Wave 3	Wave 4
Analogue Decisions	Digital Decisions	Predictive Digital	Artificial Intelligence
At key stages Capex/Opex	Converging Information Performance / Operation	Emerging Information Social Outcomes	Adaptive & Agile

EDUCATION AND SKILLS

"Social networks have demonstrated the power of connecting people with open and free forms of communication. Education must follow the same path. We do not only need to educate our own industry, the projected rapid population growth in developing countries will also need to know how to build sustainable social and economic infrastructure. How do we make sure they will not make the same mistakes we have made?"

Rachael Atkinson – Education & Skills Lead

Analogue Decisions 2010-2020

Decisions are reactive, made at key stages and re-evaluated based upon the data produced. Collaboration is acknowledged but not necessarily addressed or enforced. Work and educational environments are still focused on the professional institution's needs and requirements, rather than the product/asset outcomes or processes involved within digital transactions. The United States of America has experienced 'jobless growth', this means that there has been a growth in output but without the creation of employment. This will have a profound effect in our economy as technology enables growth in production but carries a burden on the welfare bill if we fail to up-skill the unemployed

Education

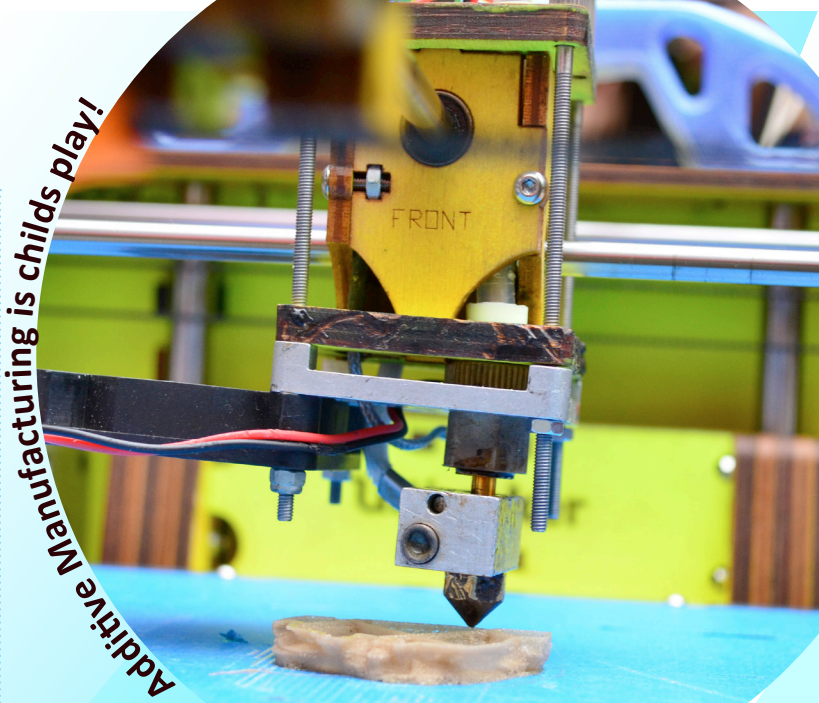
Education and learning within the built environment remains primarily siloed, with lacklustre attitudes to collaboration incorporated within curriculum programmes. The education system itself is still distinctly removed from professional practice, with courses being developed to fill interim skills gaps.

New entrants and existing construction workers/ professionals look beyond existing institutional educational courses provided, to open, mostly free, educational resources. The use of Massive Open Online Courses (MOOCs) allows learners to engage beyond geographical boundaries, and share knowledge beyond their immediate working professions and networks. This is supported by social media and knowledge sharing platforms. Within wave 1 we start to see that learners are transforming traditional CPD requirements and providers via new technological innovations; providing open access to data, knowledge, expertise and networks in place of the inadequate, restrictive and non-collaborative offerings currently available.

The influence of 'bargaining power' will shift to the students as they take a consumer role in education. This will hopefully shift the paradigm of the institution's role in certifying programmes and provide an incentive for them to collaborate and accelerate the education and industry integration in a digitally shared space. Currently the institutions are not equipped to bear any relevance to millennials, and their respective future membership potential will suffer.

Skills

Skills remain firmly within their disciplinary silos, but employers will look to sub-contract these skills requirements to individuals best able to meet their needs. Company capability assessments will be created and openly published. This will aid those organisations that are not embedding digital workflow and process into their daily process. With the decentralisation of the traditional professional institutions, construction workers/professionals will seek to broaden their knowledge and skills beyond their trade/professional background, due to unobstructed fluidity of learning. Career paths will become more flexible and interchangeable, due to a digitally-enabled construction industry.



Digital Decisions 2020-2030

This wave exists in the change period from Level 2 to Level 3 with reactive digital transactions creating a collaborative model. This wave will still be governed by the principles of analogue decisions, however, collaboration and data transactions become the driving force throughout the industry at all levels of the asset supply chain.

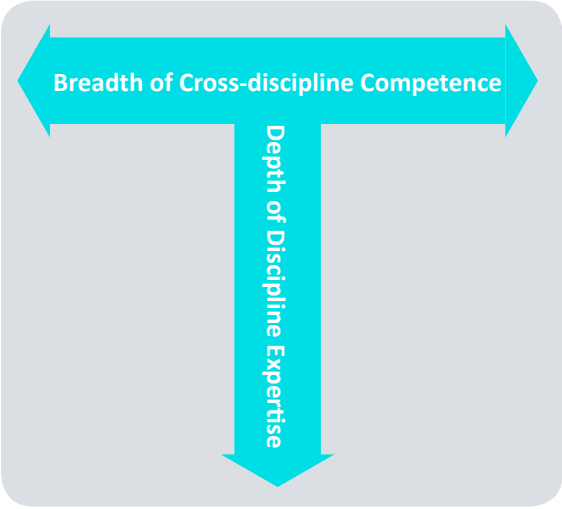
Education

Pre-defined courses with long term syllabi lasting several years, will begin to diminish in favour of smaller incremental modular learning. This will allow

the individual to select, purchase and combine these components and develop themselves in a manner that meets their career needs.

This will make learning more agile and adaptive, thus allowing the individual to tailor their development at a rate consistent with the rapid changing industrial landscape that will be beginning to emerge as a result of digitisation.

The tradition for education to cast learning by role, will diminish in favour of developing a wider understanding of processes and the relationships and interdependencies between different roles. Course curriculums will adapt to offer more 'T' shaped learning (where the horizontal line is breadth of knowledge and the vertical is the depth).



There will be more emphasis on multidisciplinary knowledge development, that is focused towards defining and achieving value added outcomes. This will require the general industry population to be educated towards employing integrated thinking.

Educational outreach programmes to Key Stage 2+ students will start to take precedence as the industry recognises that the next digitally-enabled generation of construction workers/professionals is still in early-stage education. Due to the process model of Level 3, the knowledge and capability of this digital generation needs to be focused gently towards the construction industry, to ensure that skills and ability to interact with data can be developed.

Skills

Construction roles will be diluted/hybrid versions of their previously heavily-siloed forms. There will be a significant focus on up-skilling the existing workforce. The emergence of T-shaped professionals who are able to understand data and its transfer process, starts the development of a knowledge based profession within the construction industry. Employers will also begin to look at 'non-cognitive' employees who bring new skills and processes to impact existing ones positively, possibly managed by an agile form of project management. Computational and analytical skills will emerge as a valued area of knowledge by employers, to aid in the analysis of the data produced from our virtual information and help in the future development of smart cities, which will start to emerge and develop within the next wave.

Integrated decisions result in a preference for employees with skills of an analytical background from the worlds of Science, Technology, Engineering, Art, Mathematics and Education of educators, (STEAME). This is extended from the work by STEMNET the Science, Technology, Engineering, Mathematics Network.

Predictive Digital 2030-2040

During the predictive digital wave, focus shifts from reactive collaboration to proactive integration. Digital process for the use of built assets is the norm, with multi-directional knowledge transfer throughout the asset life cycle being of the upmost importance.

Education

Education will continue to build upon themes from previous waves; and with the aid of digital and industry advisors, supporting students to create their own learning environments and career pathways. Focus will be on system networking and data analytics. Integrated learning is seen as a shared community, with many learners both using and developing the curriculum data, with two-way industry feedback and development. Institutional learning will become ad-hoc, with dynamic learning networks forming. In terms of academic intervention, we do have to warn of the danger of the reliance on big data. The historic paradigm was once that the world was flat and it took intervention from academics to shift that paradigm. If it was left to big data, there will be a hindrance to disruptive innovations.

Skills

The development and focus on integration and proactive use of data will see the skills profile of the construction industry start to shift towards workers who are able to 'make sense' of the data. Business models will develop to manipulate open data, innovation and complex asset networks, creating an asset user/asset manager industry. Skills within the industry will focus on the flow and process of information procurement and transactions throughout the supply chain.

"Economic inequality will impact our built environment globally. The gap between rich and poor will drive the political agenda for future generations. In construction however, the inequality of our workforce drives the behavior and affects the collaborative nature of working in a digitally based construction industry. How can we address the inequality in our workforce?"

Rebecca Hodson-Jones – Steering Group Lead

Sought after skills within the asset management field will surround analytics and the ability to understand 'big data', as well as the ability to make decisions across global asset portfolios. This will ultimately focus on skill requirements which involve predictive data analysis rather than reviewing the data itself.

Artificial Intelligence 2040+

Education and skills, within a fully connected construction industry, whose primary decision making needs are met using algorithms, big data and technology platforms, are vastly different to an industry that is still performing analogue tasks.

The developments of technology within education and the ready availability of big data, will produce a new generation of young professionals able to mine data from multiple sources, using existing statistical methods, and perform analytics, to show that mined data can be applied in practice immediately. Defined algorithms and rules, developed in open source forums, will automate decisions bringing us closer to fully automated asset creation. An existing example of this is the application of Bayesian statistical modelling of US Presidential Elections. The increased requirement of maintaining and improving an asset, along with the reduction of additive construction, will create a construction professional who validates automated information.

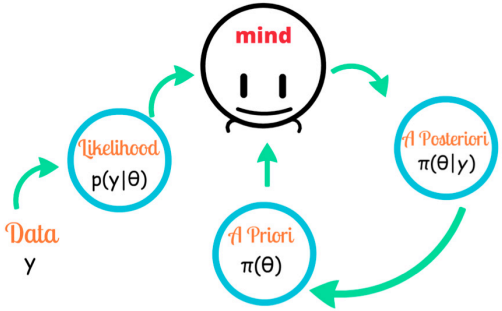
Education

The education environment within this stage is supported by the development of smart cities (integrated global economic infrastructure) and created within previous stages, and further refined. The infrastructure of these smart cities has aided the pattern of human connectivity and contribution to the surrounding environment.

Education of students through all levels of instruction will be immersive. The use of augmented reality tools, with digital tutors and global classrooms creates a learning environment that is 24/7, with year-round access, and across multiple education platforms. The requirement of institutional-approved will adapt to, open access and ready availability of learning initially created through MOOCs within the analogue and digital decision waves. Whilst education has become less restricted by immediate surroundings, virtual communities and support still exists to ensure access is maintained to relevant learning and institutions remain as certification and research centres.

Skills

During this wave the skilled workforce will be reduced to 50% of its level in 2013. There will also be a correlating expansion in educator roles to be able to support the impacts of jobless growth. Skills and roles will become more focused on the operation, maintenance and redevelopment of existing assets rather than the building of new assets. Validation of information and analysis will form the basis of the 2050 construction worker, and the increase of automated assembly and digital manufacturing will see a need for further support in designing digital systems which will allow for the creation of smarter material that ultimately responds to its environment.



Fresh BioStats - Baysian Statisitcs

TECHNOLOGY AND PROCESS

The industry is undergoing one of the largest and most disruptive change programmes in its history, as it evolves from its traditional analogue-based tools and processes to a new and more connected digital state.

It is hard to predict exactly how and for what purpose new technology will be discovered and successfully applied but observing key challenges and drivers for change is a good place to start.

Meeting the ever expanding needs of a rapidly growing population with limited time and resources, is a universal constant that will continue to influence innovation in all industries indefinitely. As human consumption continues to escalate, technologies that support more efficient and sustainable outcomes are likely to be the ones that will hold future investment potential not just for the construction industry, but in all industries. Challenges surrounding these mega trends await future generations, setting huge demands on developing technologies to unlock and generate the necessary efficiencies. When reflecting upon Building Information Modelling in its context to a sustainability race, one realises that BIM is not just about modelling or intelligent design, but ultimately represents our emerging digital capabilities as an industry, and our future potential to meet these demands.

Our digital awakening provides potential for us to integrate with technologies in other industries, with processes and applications traditionally viewed as external being open to consideration for inheritance and use in the construction domain. Consequently this section of the report identifies a number of the key technologies being researched and developed within other industries, and their potential for integration into construction methods and practices over the next 36 years.

Minecraft is an online multi-player game. It is a great example of online and open collaborative communities. Young people entering their careers today are already habitually sharing digital space and organisations need to adapt to take advantage of this as their 'cultural inertia' towards digital work flows will be very low.

Minecraft - An example of sharing digital space & collaboration

"Additive manufacturing coupled with machine learning, robotics and self-assembly will be the future of our built environment. How will we integrate the innovations made in other sectors, such as medicine, to make the best of the investment in to research and development?"

Chris Barker – Process & Technology Lead

Analogue Decisions 2010-2020

Part-integrated digital information containing aspects of construction and manufacturing information

We now have the tools available in the market to create interactive digital assets, but these tools do not all talk to one another and the processes and products can be disconnected. Leading up to 2020 we will continue to rely on highly-engineered processes to control poorly integrated data sets, and upon middleware and web applications to apply superficial connections between different sources of information.

Intelligent 3D modelling is becoming more commonplace in 2014 as the industry continues to develop its standards for an integrated digital approach to design and construction, and employer demand is also increasing for integrated operational data at handover. Employee understanding and capability with regard to the processes and technologies needed to create these outcomes is also increasing, but from a data perspective, a fully integrated data set remains work in progress .

Greater uptake and integration of mobile technology

Applications for mobile technologies and personal devices such as tablets and phones that allow the user to interact with the virtual design to read and capture asset data, and execute tasks, are on the increase. Mobile systems will continue to evolve and be well on their way to becoming a workplace standard and a technology requirement as we reach 2020.

Digital Decisions 2020-2030

Digital integration; Integrated processes, structured data and the development of predictive Artificial Intelligence

The industry should be moving beyond traditional analogue methods and working with structured and related data as a standard. We will see integrated processes and technology platforms in place that allow the efficient collation of design, construction and operational data, and a work force familiar with their application and delivery. This will enable the progressive development of predictable data sets and for other technologies to integrate more readily as a consequence. This should liberate a wave of value-added and more efficient and accurate decision making.

It is anticipated that this capability will still be limited, with a great deal of decision making resulting from interpretations and observations made by humans who are interacting with related data. 2020 - 2030 will be a period where best practice processes, and identified patterns and relationships from mining structured data, will be embedded systematically by humans to create enhanced artificial intelligence. This will bring forth a second generation of algorithms for the automated predictive digital stages of 2030+.

Emergence of intelligent assets and building operations systems that react to asset data via conventional systems

2020-2030 will be the period where SMART interactive web technologies and autonomous systems will gain real traction. Early adopters of these technologies are already exploring these opportunities. The quality and fragmented nature of current design and operations data, currently limits the value proposition for investors, but the gap between investment and return is closing.

It is envisaged that this will change when digital prototypes for assets become mainstream and operations data sets become more structured and standardised. Connectivity between "asset users" and "asset systems" will become easier to achieve with mobile network technologies such as Apple's iBeacons opening up the market in a much more scalable and commercially-appealing way. These innovations will enhance interaction between people and their built environment considerably.

Kevin Ashton's 'Internet of Things' (IoT) describes systems that will develop to the next generation of building management systems, reliant on data and connectivity to run more autonomous functions. These systems will perform more tasks and collate building use data to form a larger operational data set. Human analysis of data resulting from user – asset connectivity will play a crucial part in the development of predictive artificial intelligence during the digital stages of 2030+.

Predictive Digital 2030-2040

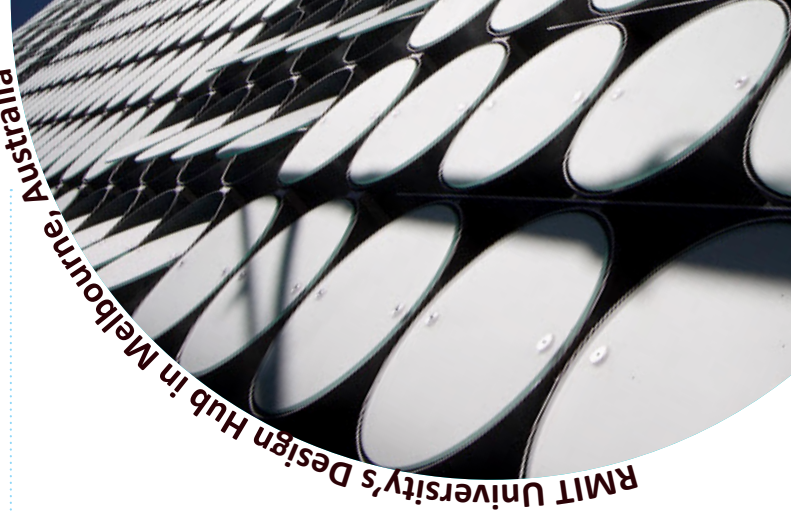
Predictive Artificial Intelligence and real-time post occupancy evaluation

Improved connectivity will have supplied new data during the converging information performance stage of 2020-2030, and the learning derived from real time building use will continue to be systematically embedded into artificial intelligence. This embedded learning will provide opportunities to develop almost instantaneous reactive decision making, and will also provide intelligence that can forecast and predict requirements for intervention. Task automation driven directly from these systems will make the widespread application and integration of robotics for planned and reactive operational tasks increasingly viable in a commercial market, and the use of these technologies may well become an absolute requirement for the SMART assets of tomorrow.

Regular use of robotics and autonomous systems

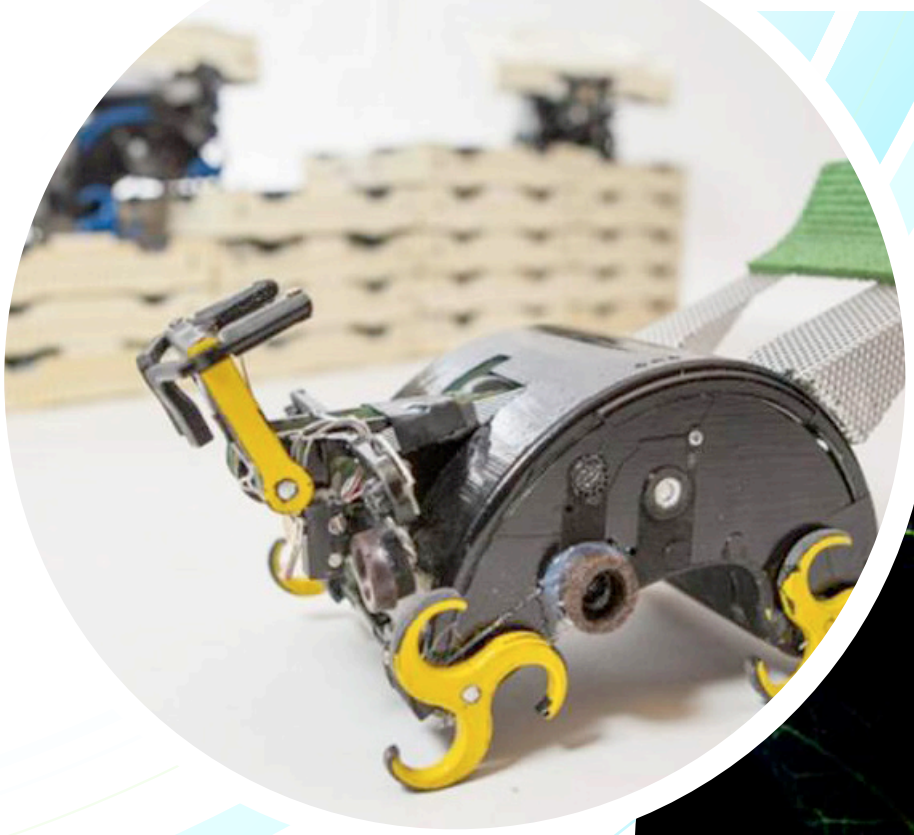
Robots are already being developed for use in the industry. While this technology is still maturing, it is likely that robotics and autonomous systems will become an increasing part of future processes and technology over the coming decades. There are already bricklaying robots like SAM (Semi-Automated Masonry robot) demolition robots, and survey drones in development.

We are finding that technology is evolving so rapidly, that not only is the prospect of assets communicating



to robots very real, but also the potential for robots to communicate with one another and conduct team oriented tasks across site and asset networks. At Harvard University, after researching the behaviours or termites in the wild, a set of autonomous robots have been produced that demonstrate what a complete artificial intelligence led construction robotics team might look like. This video provides an early insight into what the next few decades of construction might evolve towards.

So far, the process and technology section of this report has focused mainly upon the evolution and integration of highly intelligent apparatus and systems. Reviewing current innovations and technological developments in the fields of material and biological science, it appears that intelligence may be migrating into the very fabric of the assets themselves. While at present these technologies are very early in their development and need time to mature, the requirement to consider 2040+ allows us to reflect upon where this might take the industry.



Intelligent self-adapting infrastructure and materials

Adaptive Building Forms already exist and have already been utilised in commercial construction.

The façade of RMIT University's Design Hub in Melbourne, Australia contains thousands of operable PV discs that turn to face the sun to improve solar energy collection. Another example is the Foster and Partners Faculty Library building in Cambridge.

Advances continue in the field of adaptive material technology. Automated adaptation of form and composition in response to external environmental conditions is already being achieved by embedding low level intelligence directly into the materials

Artificial Intelligence 2040+

The predictive digital phase will have helped to make assets more self-sustaining, efficient and responsive to the occupants and external environment with which they interact. However, continued developments in material and biological sciences could help unlock even greater efficiencies if physical adaptation to building form and function, and automated regeneration of building components could be realised and integrated

"In 2014 the construction industry is still putting peoples' lives at risk. How are we supposed to generate an image of progressive innovation when we are not effectively deploying technology in order to ensure peoples safety? How will artificial Intelligence and Robotics influence this agenda?

Stefan Mordue – Communications Manager

themselves. Skylar Tibbits and his team at the MIT Self-Assembly Lab are creating programmable materials for self-assembly and embedding materials with programmable intelligence that allows them to change their shape and structure.

One example is the collaboration with Geosyntec to create pipes that can change shape or form to accommodate or manipulate fluid flow by expanding or peristalsis.

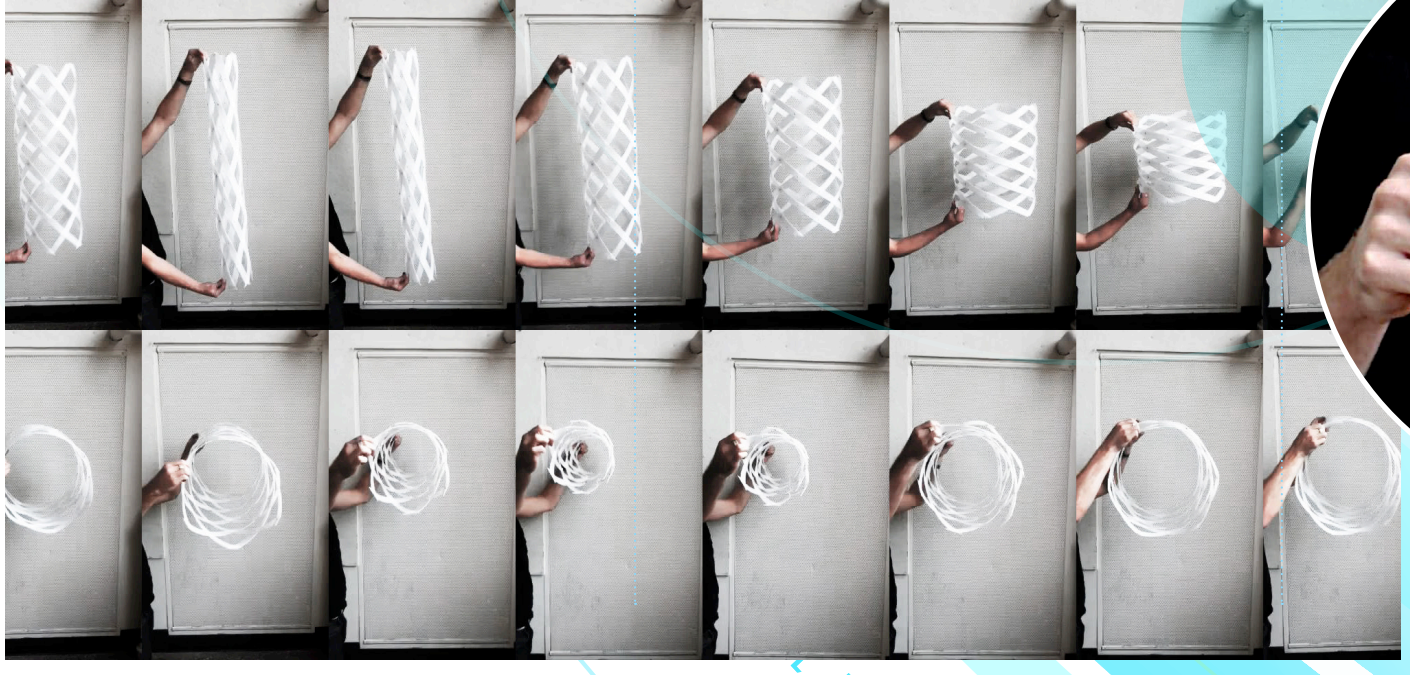
Biological Infrastructure

Biological Infrastructure already exists and has been utilised in commercial construction. The BIQ House uses a "bioreactor façade" design, comprising glazing panels that contain microalgae that reacts with sunlight to produce biomass as a fuel source for the building.

Future integrations and advances in Synthetic Biology may well lead to manufactured biological materials that can be used in construction. The development of sensory technologies for asset controls to measure, collate and react to environmental data is a potential future prospect. Interestingly, similarly to construction, recent advances in computer modelling and the ability to visualise, simulate and optimise design in this field of science is helping achieve these breakthroughs.

Sustainable "bioparts" connected to web services via advanced sensory technologies could one day result from future developments and integrations in the fields of synthetic biology, biomechanics and regenerative medicine. Such collaborations with industry could enable data to be recorded, transmitted and transacted using synthesised materials and protein carriers, as parts of simple sensory building controls. Biologically-based biosensors and control systems such as AND and NAND logic gates (electronic logic switches) have already been produced enabling bioparts in electronic circuits.

For more information regarding Synthetic biology and how the children of today and the "maker movement" are generating positive outcomes in this field, see Synthetic biology designing tools for a better world.



CULTURE OF INTEGRATION

"We cannot deny what our industry has achieved when constructing landmark projects, and the outcomes have been positive. But in most cases the process behind these achievements has been muddled through and failed to capture our learning. How can we ensure a consistent performance in design, production and in operation? What part does integration have to play?"

Wes Beaumont – Culture of Integration Lead

The future of the construction industry, and the value that is created, will be based around behavioural economics and the ability of construction professionals to integrate collaboratively, create knowledge and contribute to positive organisational cultures. Economic rewards will exist for those behaving in a collaborative manner, from macro to micro-level integration teams with shared risks and rewards. This culture of integration will lead to the removal of exploitation, reward collaboration and encourage leadership. Motivation will improve due to smaller teams, increased empowerment and more equitable work arrangements. This will be based around fairer payment mechanisms due to increased transparency, and earlier engagement that leads to improved knowledge creation.

A culture of integration will require continuous change as the industry moves through waves up until 2015 and beyond. This change, based on the Deming's Cycle (Process of Plan, Do, Check and Act), will use datasets of information spanning the entire lifecycle across all disciplines. Near-instantaneous feedback loops, akin to those used in the motorsport industry, will identify the effect of changes and assist in the facilitation of the knowledge economy within construction. Continuous change will also occur in supply chains, with reduced complexity and a move towards flatter hierarchies. This change will lead to nano-corporate entities and the reduction of organisations performing only segments of a project. A return to vertical supply chains will facilitate greater collaboration and joint ventures, with special purpose vehicles created for mega projects. At the micro level small teams will encourage autonomy and empowerment as more responsibility is provided. This will lead to the end of traditional sub-contracting practices and a move towards the return of the master builder.

Open supply chains will be paired to their most appropriate peers based on the aggregate of data on performance, inter-personal suitability, availability and specialism. Whilst technology and education will evolve due to improvements in science and teaching, the procurement models will simplify, with a change back to simple appointment processes as risk models shift, due to the huge increase in transparency and risk allocation strategies.

An example application of nano-corporate practices are the use of mobile phones as a means of secure payment in developing economies, such as Africa. Also known as M-Pesa (M for mobile, pesa is Swahili for money). This method of payment has emerged from the difficult cultural conditions around the fair payment of goods and inaccessibility of good quality financial services. This has opened up new business streams for mobile phone operators and supplied a great benefit to local communities and will challenge conventional financial institutions.

Analogue Decisions 2010-2020

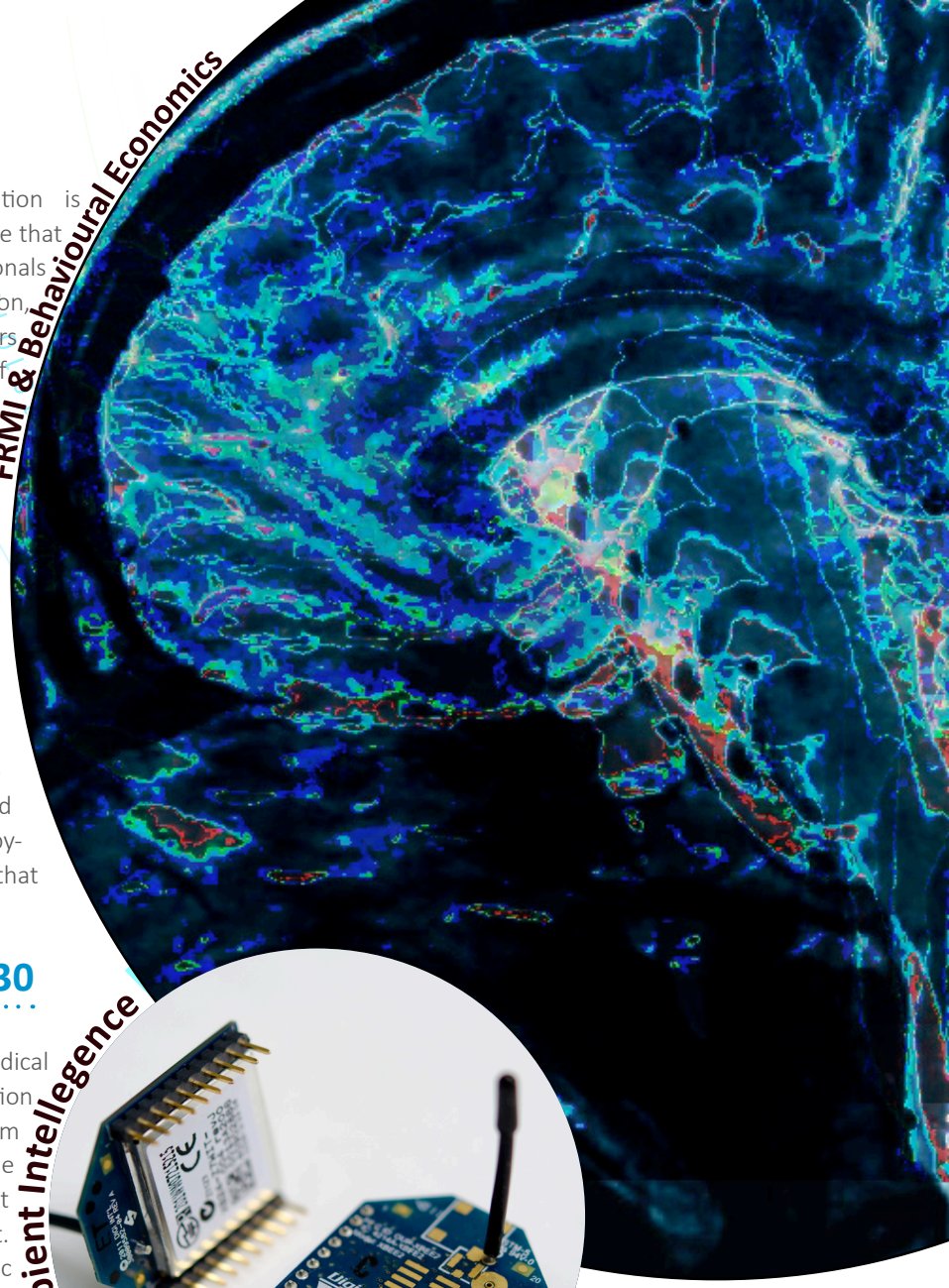
The first wave is typified by manual inputs and management of outputs. In his 1962 report Sir Harold Emmerson commented, “In no other important industry in the world is the responsibility for design so far removed from the responsibility for production”.

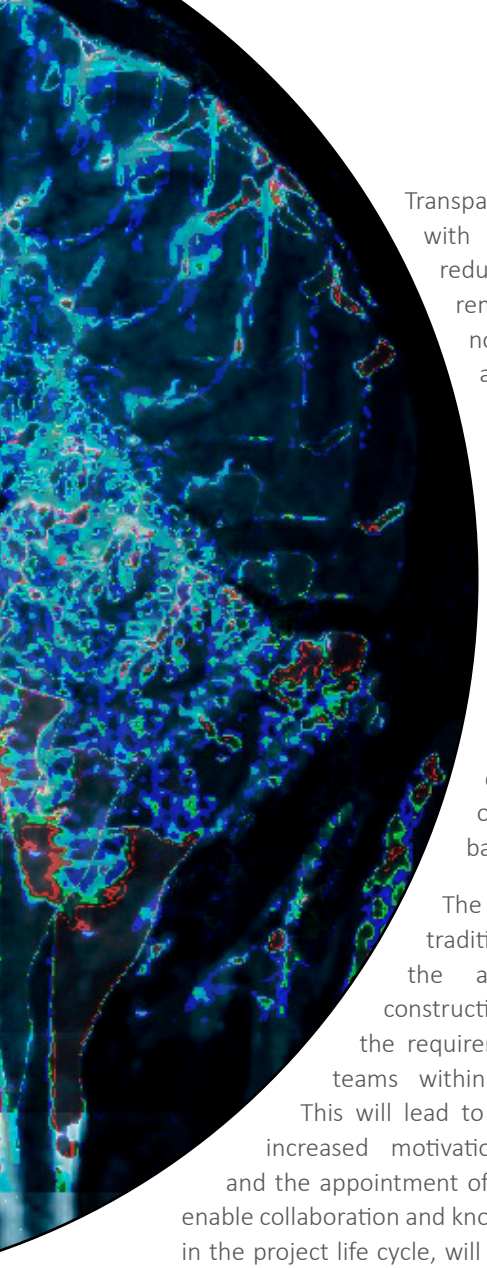
Whilst it is true that this gap has been reduced, there still remains a lack of integration within the construction supply chain, specifically between design, construction and operations. Currently the industry is archaic, non-transparent and lacks innovation, in both technology and process. A culture of integration is fundamentally reliant on the acceptance that most, if not all, construction professionals are interdependent. Fragmentation, exploitation and egocentric behaviours are a detriment to a culture of integration.

Currently there are barriers that severely undermine the possibility of a completely connected industry, one which encourages beliefs and behaviours which create integrated teams and altruistic behaviours and place emphasis on shared goals, objectives and rewards. As antiquated generations move into retirement leading to the end of this period, there will be an emergence of integrated solutions which resolve the ‘Baby-boomer’ ideology, and thought belief that currently exists.

Digital Decisions 2020-2030

This wave exists in the midst of a radical change in the industry, with the adoption of BIM Level 2 and the transition from manual analogue processes to the automated input and management of outputs in a digital environment. However, this will be based on static rule sets, governed by existing processes and procurement, and project delivery strategies.





Transparency here will improve, with shared information reducing decision lines and removing waste, most notably in wasting time and the need for re-work. Re-work can be virtually eliminated with the reuse of data spanning across all disciplines throughout the entire life cycle.

Moving towards macro level integration based on shared information will require new forms of contract to fill the void once held by the 'claims-based culture'.

The breakdown of traditional disciplines and the amalgamation of pre-construction activities will negate the requirement for large disparate teams within a single organisation. This will lead to more responsibility and increased motivation. Early engagement, and the appointment of design consultants to enable collaboration and knowledge creation early in the project life cycle, will become the norm at the back end of this wave. This will encourage and foster the growing nature of the SME and digital start-up which will flood the industry at this time.

Predictive Digital 2030-2040

Following on from wave two, which primarily concerned collaboration, this wave will seek to promote integration. Additionally wave three will see data being used pro-actively rather than reactively, which is likely to occur in wave two. Using digital technology, the industry will see the commencement of automating internal and external transactions based on rule sets. This move away from reactive strategies towards focused proactive strategies will be partly due to the huge increase in knowledge of the supply chain and the socio-economic relationships that exist between macro- and micro-level personalities. Too often, traditional transactional contracts foresee a single result - the value of a future outcome in exchange for money. Relational contracts will flourish in this wave as traditional methods of generating profit, including exploitation, are stifled.

"Transactions and risk will always need effective management. Our legal and contractual framework in construction will need to adapt to suit digitally connected and automated business practices. How will we ensure that the institutions of construction are integrated and fit for purpose in a real-time procurement industry?"

Khalid Ramzen – Technical Manager

Design consultants and principle constructors will be appointed simultaneously, early in the life cycle, to enable concurrent working at the outline business case stage. Higher levels of vertical integration will reduce sub-contracting, removing horizontal interfaces, which restrict the flow of information. The reluctance to share information further down the supply chain due to a strong selfish mentality will cease, as organisations are enabled to conduct business as a single entity, working simultaneously with minimal barriers, sharing resources and creating common objectives.

A focus on relational contracting supports this recommendation using multi-party contracts to discourage legal disputes and costly litigation.

In terms of generational shifts this wave will begin to see a transfer skill and knowledge base as roles will begin to dissect and become individualised, whilst removing their traditional isolated areas of business. This shift will be due to the changes in educational, self taught processes which engage individuals' unique skillsets and ensure that these people are embedded in the construction industry in completely differing ways.

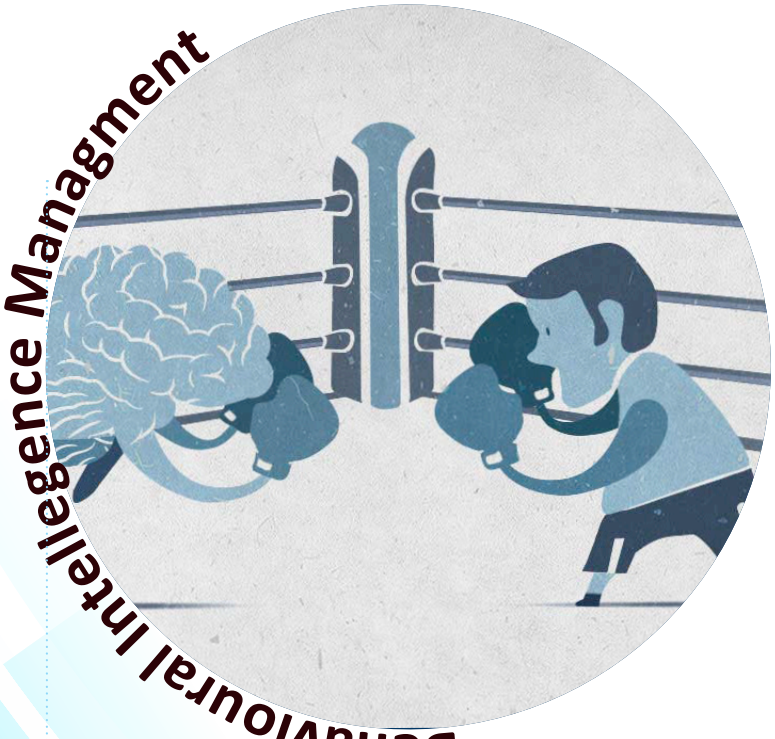
Culturally this shift will change how we collaborate, how we transact on this collaborative method, and how our digital conversations can begin to allow for a more unified and solidified approach to building projects.

Artificial Intelligence 2040 +

A fully connected industry is one that understands the value of technology as a means of communication. Google and Facebook became a success by sharing data and information, more often than not, created elsewhere. In the fourth wave employment of labour will be focused on the validation of data and to ensure that the machine is working. Procurement will be automatic with the use of adaptive rule sets based on a Bayesian approach. The Bayesian approach is how machine learning is developed in to artificial intelligence, enabling our work flows to become free of laborious information transfers and provide a framework to employing a guided discovery approach to design and client / community engagement.

This level of engagement will utilise data sets of information relating to the entire life cycle and stakeholders will identify the most appropriate member of the supply chain to undertake tasks. This will be based on continuous performance measurement to finite detail; not just cost, time or quality.

Ultimately supporting an environment that is inclusive of end-users and utilises machine learning techniques to enable social and economic infrastructure to deliver the best outcomes.



"Typical large building projects (£20-£25 million) involve main contractors managing around 70 sub-contractors. The industry consists of mostly SME firms (over 90%) and their interactions with tier 1 supply chain members are labour intensive in terms of establishing scope of works and procurement. What will happen when these transactions occur in real-time?"

Ian Aldous – Programme Manager

Recommendations

As a result of our research over the last 20 months we have established that there are key areas for consideration for construction industry organisations and academia.

These recommendations should be considered in close context with not only current industry thinking, the reader should question how they are going to build the foundations for future generation of leaders.

We have categorised our recommendations in to research trajectory for academia to consider and focus for organisations.

1. Cyber Security

- Data Residency - Organisation

- Encryption & Penetration - Academic

We have highlighted the opportunity and risks in a digitally integrated network of social and economic infrastructure.

Organisations need to review their data residency, integrity strategies and agreements to proactively defend our digital & physical assets from cyber-attacks. Current practice is to throttle access, this creates inefficiencies and inhibits collaborative working.

Academics need to research data encryption and security access techniques in the context of the built environment especially operational data sets. OpenSSL cryptography and cryptography in general needs to be developed further to secure internet enabled infrastructure.

2. Interoperability for Smart Cities.

- Dynamic infrastructure - Organisation

- Machine learning & adaptive efficiency - Academic

The integration of intelligent infrastructure to produce smart cities is well documented, but organisations need to review the interoperability of the products that their supply chain installs on to projects. We recommend that organisations conduct a review of their supply chain strategies to analyse the interoperability of technology and their redundancies including physical connections and associated interface protocols. Academics must consider the impact of their innovations and ensure that the considerations for future use include the integration into globalised networks extending into microbiological impacts.

3. Behavioural Intelligence Management

- Pre-occupancy evaluation - Organisation

- Knowledge based engineering - Academic

There are two sides of behavioural intelligence. The first is a base set of assumptions and data used in the assessment and evaluation of future projects, by incorporating the behavioural elements of the build environment into net present value calculations and design processes. The second is the behavioural management of labour. We recommend organisations first consider the behavioural intelligence of their end-user workforce as they will be unable to design with behavioural intelligence in mind without the appropriate orientation. They will then be able to build behavioural bases to their organisational and production processes.

Academics must incorporate the extensive work already achieved in psychology, much like the creation of behavioural economics where two social sciences have integrated to produce a new field of socio-economic built environment studies.

4. Nano-second Procurement & Performance.

- Optimisation & Big Data Techniques - Organisation

- Improved Asset Utilisation - Organisation

- Predictive Analysis & Configurators - Academic

Lightning speed transactions are currently in existence in the stock market. Stock prices are adjusted as soon as new information is available. Construction procurements are already exposed to exogenous market shocks, such as the commodity markets. We advise organisations to accelerate their digitisation of business management and enterprise resource planning systems to be ready to trade in the nano-second market.

Academics need to research the commercial agreements and risk transfer practices around high speed transactions and build the foundations of simulation scenario training applications.

5. Biological Complexity

- Smart materials - Academic

- Self-Assembly - Academic

- Regenerative Construction - Academic

Construction materials will become complex as will their interactions with interfaces at a micro-molecular level. This will require ‘design management’ to become super accurate and scientific in practice.

We recommend organisations to include biology and chemistry in their recruitment selection process to manage the infrastructure-human interface, for example technology that is embedded within our bodies.

Academics will need to research the impact on design liability for static or regenerative materials that self-assemble.

6. Life-Long Learning.

- Free, Open & Online - Organisation

- Immersive - Academic & Organisation

- Industry & Academia. Integrated

The notion of a career for life has already degraded and the pace of change has led to developed countries leaving their population lagging behind technology (see jobless growth). This will put strain on the welfare bill and cause higher occurrences of poor health and increased crime.

Organisations must take responsibility for adequately adapting the skills of their existing workforce by utilising MOOCs and other flexible learning systems.

Organisations and academia must integrate to accommodate life-long learning and integrity of that learning.

7. Consumer Access Economy & Space Travel.

- Service business models - Organisation

- Building out of gravity - Academic

Consumer level autonomous vehicles are on the horizon and all those who would be driving will be free to produce or consume on the go. This is just one example of a rental, access based consumer activity. Consumer space flight is also on the horizon and would see attractions and accommodation in space. Constructing in space will probably see a step change in construction innovation. Organisations are recommended to review their procurement strategies to take advantage of access based services, such as cloud computing and integrative project spaces. They will also have to consider what impact extra-terrestrial construction will have on 'gravity-based construction'.

Academia is recommended to review their educational spaces to support group/project work in these types of environments.

8. Sector Skill Migration.

- Skill warfare - Organisation

- Jobless growth - Organisation

Technology has enabled economies to grow in terms of output but without creating any employment opportunities. This will position organisation and universities to battle for the desirable skills, hence our recommendation for industry and academia to integrate.

As a function of the interdisciplinary integration of networks and smart cities, skills would enjoy the same level of integration. Organisations need to map their own organisational information requirements against their clients and supply chains to assess the missing skill areas and look outside the traditional skills sets, utilising demand side employment contracts that reflect career demand and meritocracy.

Academia needs to address the balance of discipline specific skills with collaborative awareness and the information requirements of others.

9. Robotics and Autonomous Systems

- Skilled labour & system maintenance - Organisation

- Automation In the supply chain - Academic

50% reduction in skilled labour for construction is the basis of jobless growth in construction. Skilled labour will be needed to maintain autonomous systems and will see the field population reduce to a minimum level. This should see the risk to site operatives be removed from the construction process but a rise in the risk of people plant interfaces in complex operations. Organisations should consider automation and design for manufacture strategies as early as possible in the asset lifecycle, and how algorithmic methods can be used to determine the exploitation of mechanisation. Academics will need to research an auditable standard for autonomous construction vehicles and their operating systems within the context of an evolving construction environment.

10. Business in the Future.

- Talent as commodities - Organisation

- Demountable organisations - Organisation

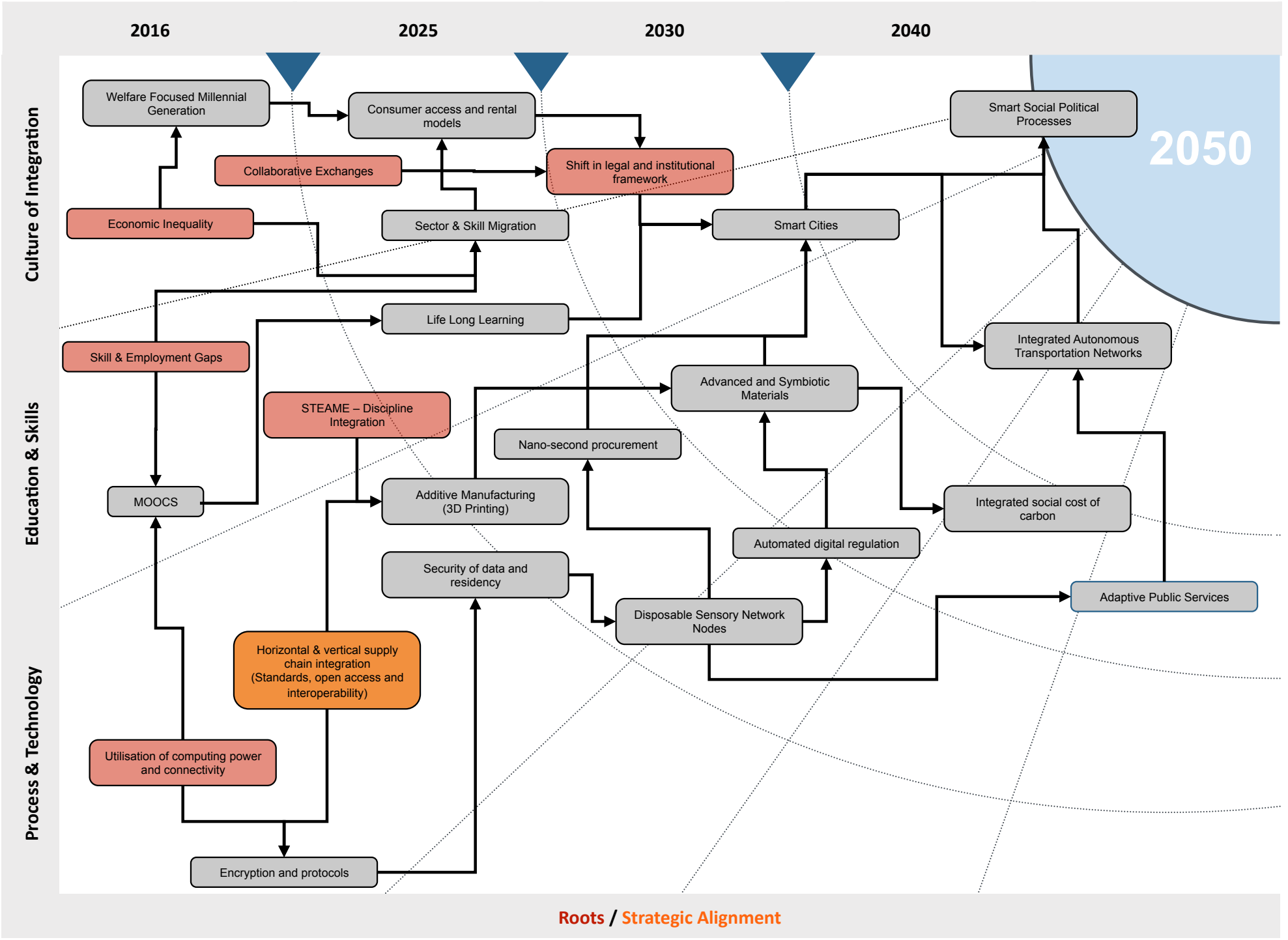
- Mobile Capital - Organisation

Combining education and skills, process and technology and a culture of integration there is clearly a shift in sustainable business models on the horizon.

Adaptive networks of skills with rapid mobilisation and easily demounted will form project teams. These teams will have an understanding of the value of their human capital. This will see a shift from employers owning employees to entrepreneurs trading talent as a commodity. This combined with the democratisation of financial institutions (as seen by M-Pesa's in Africa) will see fewer individuals being employed directly.

Organisations are recommended to determine career pathways which are T shaped and enable migration between disciplines to meet resource supply.

Academics need to develop their relationship with their students away from a consumer model to a human capital development and trade relationship supporting the integrative relationships with organisations.


2016
2025
2030
2040
2050
Culture of Integration
Education & Skills
Process & Technology
Welfare Focused Millennial Generation
Consumer access and rental models
Smart Social Political Processes
Collaborative Exchanges
Shift in legal and institutional framework
Economic Inequality
Sector & Skill Migration
Smart Cities
Life Long Learning
Integrated Autonomous Transportation Networks
Skill & Employment Gaps
Advanced and Symbiotic Materials
STEAME – Discipline Integration
Nano-second procurement
MOOCS
Additive Manufacturing (3D Printing)
Integrated social cost of carbon
Automated digital regulation
Security of data and residency
Adaptive Public Services
Disposable Sensory Network Nodes
Horizontal & vertical supply chain integration (Standards, open access and interoperability)
Utilisation of computing power and connectivity
Encryption and protocols
Roots / Strategic Alignment

Terms & References / Glossary

Adaptive & Agile The built environment to read and react to its own data with minimal human intervention.

Additive manufacturing 3D printing (printing with materials to create physical objects).

Advanced Robotics Robotics with the ability to undertake detailed tasks using learned information.

Analogue Decisions Manual decisions that require human interaction.

Artificial Intelligence Ability to make decisions based on complex algorithms/coding to produce intelligent outputs.

Automated regulation checking and audits Ability to automatically undertake quality assurance checks by using complex algorithms/coding with minimal human intervention.

Autonomous Vehicles Vehicles that can drive themselves.

BE Built Environment.

BIM Building Information Modelling.

BIM2016 The point at which the UK Government has mandated Level 2 BIM.

BIM2050 A group set up in conjunction with the CIC to look at future trends to ensure that we have an industry fit for purpose in 2050.

Capex/Opex Capital + Operational expenditure.

Totex Total Expenditure (Capital + Operational expenditure).

Carbon costing The process of calculating the carbon in build assets (both embedded and live).

Common data environment A single source of information for any given project, used to collect, manage and disseminate all relevant approved project documents for multi-disciplinary teams.

Consistent data exchanges The development of interoperability and standardisation to ensure that information exchange functions are coherent and uniform.

Construction Strategy 2025 The UK Government's strategy to 2025.

Continuous Emergent Iteration Repeated and automated revisions based on stated parameters.

Converging Information This is the tendency for different information platforms to evolve toward the production of similar outputs performing similar tasks

Cyber physical systems A system of collaborating computational elements controlling physical entities.

Data verification and validation Confirming that the data is correct.

DFMA Design for Manufacture & Assembly.

Digital Decisions Automated decisions that do not require human input.

Emerging Information This is a field of information that broaches new territory in some significant way, either in the basis of its formation or the way in which it captures outputs.

Feedback cycle The time taken to receive, process and action information.

Gamification Use of game thinking and game mechanics in non-game contexts to engage users in solving problems.

Graphene Pure carbon in the form of a very thin, nearly transparent sheet, one atom thick. It is remarkably strong for its very low weight and it conducts heat and electricity with great efficiency.

Gross fixed capital formation A macroeconomic concept used in official national accounts.

Industrial 3D Printing Printing with materials to create physical objects on an industrial scale eg housing.

Information time horizon A fixed point of time in the future at which point information processes will be evaluated.

Interoperability Open source service based technology model. The ability for differing technology solutions to be compatible and communicate with each other.

Level 4 Rule based design and analysis Continuous Emergent Iteration , Smart citizen, Nano corporate.

Modularised construction Forming built assets from a set of standard parts.

Nano corporate The concept that future corporations will grow from nothing very quickly, serve a specific function, and then come to an end.

Non-additive construction Construction that re-uses existing resources rather than adding new ones.

Performance / Operation The need to be able to look at operational efficiency of built assets.

Post occupancy automation and productivity The ability to monitor in a real time basis the performance and operations of a built asset.

Predictive Digital The position whereby information predicts solutions in an automated manner.

Quantum Computing Traditional computing uses a binary transistor based method (zeros and ones) of processing of machine code for computational tasks. Quantum computing uses subatomic particles that have a higher magnitude of states enabling parallel computational tasks. Although in its infancy and expensive where a single unit will fill a room with low computing power, it did not take long for modern system to become small enough for use by the masses.

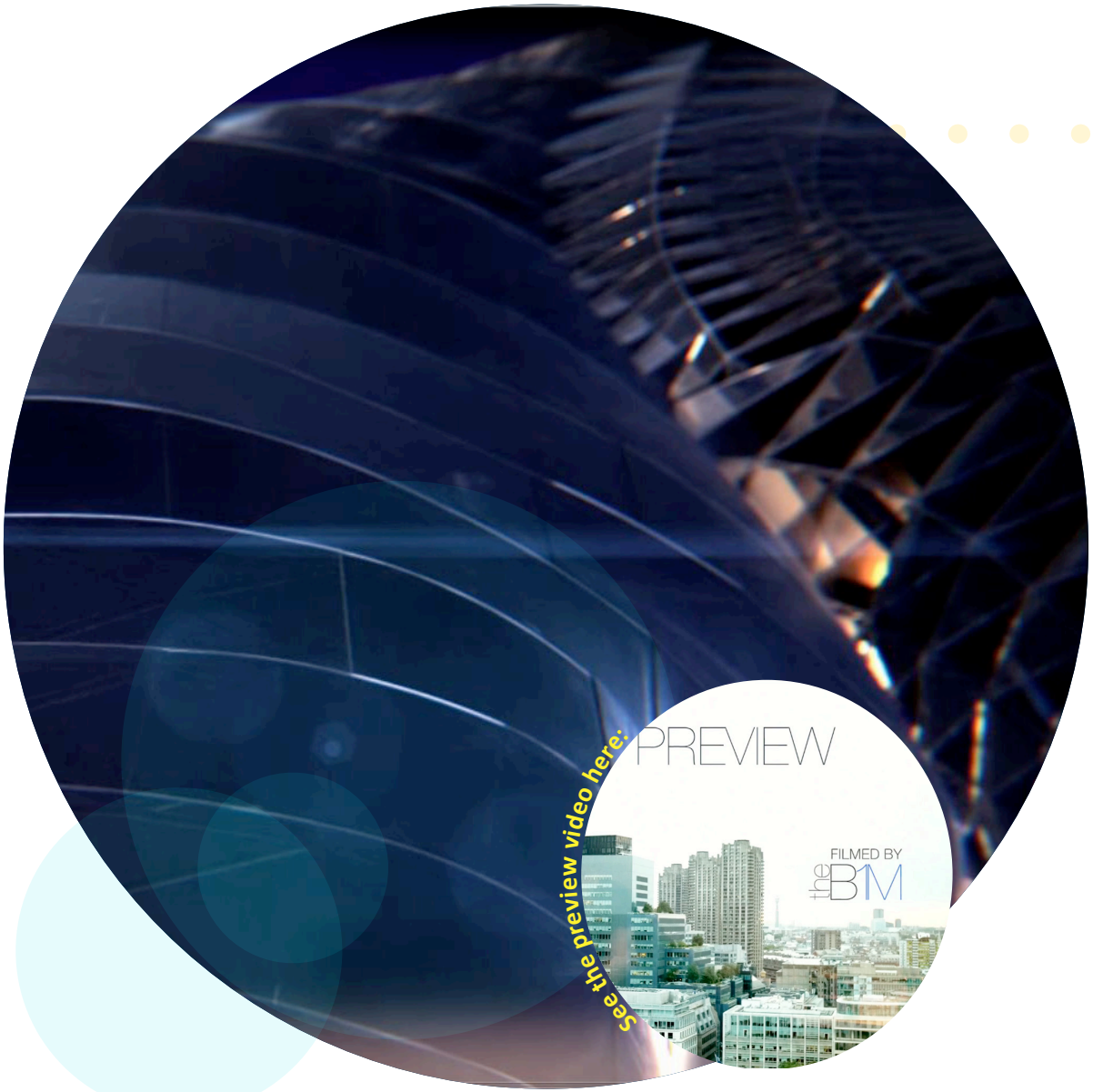
Query non-graphical digital data Ability to question and have responses from information .

Representative 3D environment A digital version of a the built environment developed for relative purposes.

RFID Radio-frequency identification.

Self Assembly A process in which a disordered system of pre-existing components form an organised structure or pattern as a consequence of specific, local interactions among the components themselves, without external direction.

Self Procurement A process in which machine learning and digitised assets with a digital market enables buyers to use automated procurement systems. Facilities automatically ordering bulbs when they break for example.



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Construction Industry Council,
26 Store Street,
London,
WC1E 7BT
Tel: 020 7399 7400
Fax: 020 7399 7425

Lead Authors: David Philp & Neil Thompson