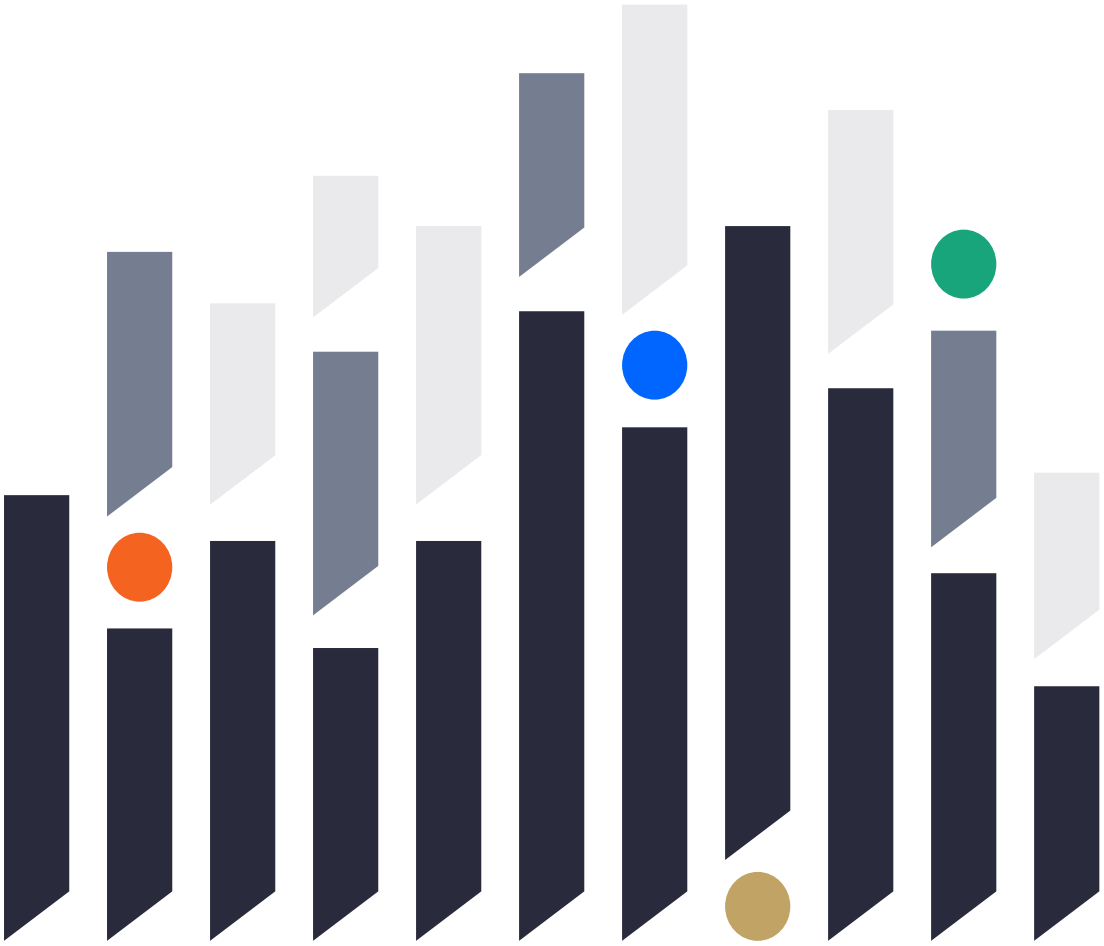
Centre for Digital Built Britain

Research Agenda and Landscape



Workpackage 5: Making the digitally enabled services and supply chain work

V2.1 Released

urban innovation labs

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Executive summary

The assets within the built environment underpin over £600bn of value each year to the UK economy, with millions of people and thousands of companies involved in this value creation. The sector is complex, diverse, fragmented and under tremendous pressure to improve productivity and remain financially viable and stable. The supply chain has remained largely unchanged for many years, while the world has moved on with different needs and expectations emerging at a time where the use of digital techniques is revolutionising every other sector in the UK.

This workpackage explores the capabilities needed: by government, by those involved in the specification, design and delivery of built assets and across a portfolio of services, through-life, for businesses and citizens, and the capabilities needed by government, business and citizens to best derive value. It also reviews how such operations will be managed and enabled within specific supply chains, how organisations will work together, and how services will interact with the built environment to *make the digitally enabled services and supply chain work*.

This report has identified 18 themes across diverse sectors of education, healthcare, transport and energy in the time horizon 2040-2050. These themes will require 21 capabilities to be developed, ranging from defining causal relationships from assets to service outcomes, through to identifying where value is enabled throughout the lifecycle. The state-of-the-art for these capabilities has demonstrated the digital enabled supply chains for the manufacturing sector were well understood, while for service and service reliant on the built environment, there is very little research available. The research available emphasised the importance of information to underpin the development of new delivery models. The new delivery models suggested focus on the development of value networks coalesced around outcomes rather than the classical supply chain we have today. Since the supply chains tend to form around the contractual arrangements, the contractual arrangements currently used were analysed; this illustrated a number of the challenges and opportunities that exist when defining outcomes and the factors to be considered in their determination. The research illustrated that there is a potential agreement form to realise greater levels of value from alliances where outcomes are aligned and where there is shared risk and reward.

There are very limited universities or other institutions working in this area of capability development. There is research in adjacent areas that may be leveraged, but it has highlighted a research gap that needs addressing if the required capabilities are to be developed within the time horizon.

A series of stakeholder interviews were conducted at different levels within the supply chain and at stages in the lifecycle to understand the current capability, where they see the sectoral challenges, and the ambition for development to address the challenges. The principal observations of this engagement were:

- A greater understanding and definition of the problem to be addressed is required, to avoid following over-hyped trends.
- The concept of outcome-based contracts and delivering value are understood as concepts, but it was foreseen that there is a challenge of defining an outcome in terms that can be contracted and monetised.
- Those participants who had experience of outcome-based contracting noted the need for simplicity.
- There is an agreement that some assets are closely coupled to the service and others are not. Focus should shift to those scenarios where a close coupling exists, the outcome articulated, and the value leveraged.

- There is an appetite to accept the risk of outcome achievement, if it is balanced with sufficient reward.
- It is recognised that data is fundamental to achieving these new capabilities and data governance is essential.

21 capabilities were identified that consider the future needs of the UK, the state-of-the-art knowledge in these areas and that reflect the current capability of the market. These capabilities have been consolidated into four principal capabilities that need development for the UK to respond to the requirements in the time period 2040-2050, and are as follows:

- The causal relationship between the infrastructure and value of service socioeconomic outcome is defined. This capability will enable the attributes of an asset which support the creation of value of the outcome to be identified and traced though the lifecycle.
- The structure, commercial value and liabilities of the information is defined. This capability creates the data model with sufficient integrity and security, along with the process obligations that mean it can be used for commercial transactions.
- Supply-chain aligned to value creation. This capability identifies the networks of value creation and will identify a new landscape for supply chains focussed on delivering outcomes.
- Organisations have the capability and capacity to use digitally enabled methods to deliver value within the supply chain and to society. This capability will provide the capacity of skills and competence necessary to define, use and benefit from the digital techniques in the supply chain.

There are not any demonstrators attributed to these capabilities. Therefore, the research looked at where contractual relationships have been established throughout the asset lifecycle to see how a data driven approach to the supply chain has realised service value. This illustrated that an Alliance approach, where the parties are aligned and work together to achieve shared outcomes with a proportionate risk and reward, would be the ideal arrangement. The alliances identified are focussed on discreet areas of the supply chain like design and build, or maintain and operate, rather than an end-to-end approach at this stage.

For the Centre for Digital Built Britain to develop the national capability needed for 2040-2050, this workpackage recommends the following actions:

1. Accelerate current and future high value use cases

   This subject is heavily dependent on the commercial arrangement of the supply chain. While theoretical assessment and recommendations can be made, it is often only when there are live examples the real challenges surface and innovation emerges.

   It is recommended that a high value use case is identified from the current portfolio of contracts that transcend all stages of the lifecycle and a ‘shadow’ structure is developed in combination with the existing parties to create and stress test a parallel digitally enabled value network.

   It is recommended that development is required to develop the digitally enabled value network for an as-a-service model, in anticipation of future deployment. It is anticipated that any of the emerging as-a-service business models with a close coupling between the asset and the outcome would be an ideal candidate for future deployment, for example mobility or energy. It is considered a prerequisite for these as-service models to have a digitally enabled

value network, otherwise it will be difficult to establish and contract the basic relationships that form the foundation of the service and successfully scale-up.

2. Initiate collaborative research

There is little existing research in this area, and it does not naturally sit in traditional definitions of schools or departments. The research needed is at the intersection of engineering, law, humanities and the business school, and will need all of this expertise to collaborate if the fundamental and applied questions are to be answered. These being:

- Understanding loose and close coupling of assets and service outcomes.
- Identifying where value is created in closely coupled assets and service provision.
- Defining the causal relationship between the infrastructure attributes and value of service socioeconomic outcomes.
- Creating the data structure and determining commercial value and liabilities of the information value chain.
- Creation of the legal principles for value network.
- Determining the behaviours required for the digitally enabled value network to flourish.

3. Support capability development

A move to a digitally enabled value network will require support if the capabilities needed with clients, supply chains and places of learning are to be established in sufficient quantities to make this approach viable. For example: in the development of standards, guidelines and codes of practice; for training; for showcasing lighthouse projects; and for building networks of practitioners.

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1. Introduction

The assets within the built environment underpin over £600bn of value each year to the UK economy, with millions of people and thousands of companies involved in this value creation. The sector is complex, diverse, fragmented and under tremendous pressure to improve productivity and remain financially viable and stable. Recent events with large organisations like Carillion folding highlights the challenges involved in the sector: how dangerous it is to accept levels of unmanaged risk or be part of a supply chain where liquidity is in question, without the capability to manage.

The use of data to create insight and make better decisions is considered a key enabler in improving the efficiency and effectiveness of the industry. However, it needs to be used with caution. The authors believe that digitalisation within the built environment is an over-hyped term purporting to be answer to all challenges the sector has faced. While reports by many of the leading consultancies show correlation between productivity and digitalisation, the causality of the relationship as a ubiquitous remedy is yet to be established. There is a danger that organisations and their supply chains become transfixed on digitalisation without understanding what problems they are seeking to solve or outcome they are working towards achieving. It also draws into question how productivity is defined, and the effort expended to produce an output or achieve an outcome.

There is substantive evidence of the efficacy of digitalisation on the supply chain for the built environment. Digitalisation actually works for the supply chain, but whether it is efficient or effective is another matter as it depends on a variety of factors including objectives and incentivisation. It is believed if an organisation is rewarded on time and materials, the focus will be on the efficacy of the work they are undertaking rather than the efficiency or effectiveness, as there is no motivation.

If an organisation is working to a traditional output-based contract, they are incentivised to reduce the cost of the works done or to increase the volume of work to do. The use of digitalisation will improve the design process, enable better planning of the works and sequencing of the supply chain, capturing errata during commissioning and handing-over information to the maintainer. This is where it is considered that the majority of the effort and solutions are focussed - completely understandable when the contractual landscape is incentivised to do more for less.

Whereas, with an outcome-based contract, the client needs to have a clear, structured and tracible understanding of which outcomes they seek to achieve, the value of the outcome, and the impact of the constituent elements of a solution (goods or service) on realising the outcome. This incentivises the supply chain to be effective, focussing on the right goals and achieving these in an efficient manner. This is more challenging, and is where the greatest benefits of the digitalisation of the supply chain will be realised.

The authors note that while the supply chain could be totally optimised without an understanding of the purpose of the transactions or result of the outcomes, there may be unintended consequences emerging and the socioeconomic objectives left underserved. To ensure this does not emerge, the context and impact of one system optimisation within all others is of critical importance.

1.1. Research question

This workpackage will explore the capabilities needed by government: by those involved in the specification, design and delivery of built assets and across a portfolio of services, through-life, for businesses and citizens, and the capabilities needed by government, business and citizens to best derive value. It also reviews how such operations will be managed and enabled within specific

supply chains, how organisations will work together, and how services will interact with the built environment to make the digitally enabled services and supply chain work.

1.2. Methodology

The research will be structured around identifying:

- What new capabilities the UK will need.
- Where the basis for such development and demonstration exists today.
- The research, development and demonstration necessary to build, deploy and disseminate such capabilities.

Since the scope of the Centre for Digital Built Britain is broad, this research will focus on healthcare, education, road transport, and electrical energy. These have been selected as previous research has suggested that healthcare and education are loosely coupled assets and service, whereas transport and energy are considered to be tightly coupled. This will stress test the capabilities identified and guide the centre to where most impact can be achieved.

2. What new capabilities the UK will need?

This section will identify the macro-economic, societal and technical changes foreseen in the time period 2040-2050 and describe the capabilities needed to define, create and manage assets to create value for education, healthcare, energy and transport.

There are many definitions of supply chain and value chain, and they are often used interchangeably. For the purposes of this workpackage a supply chain describes the actors and their relationships, and the value chain is the process view of an organisation. A supply chain is a system of organisations, people, activities, information, and resources involved in moving a product or service from supplier to customer. How an organisation performs these tasks and transforms the constituent elements into a proposition which is valued by the market is the value chain[1].

The idea of the value chain is based on the process view of organisations: the idea of seeing an organisation as a system, made up of subsystems each with inputs, transformation processes and outputs. Inputs, transformation processes, and outputs involve the acquisition and consumption of resources – money, labour, materials, equipment, buildings, land, administration and management. How value chain activities are carried out determines costs and affects profits[2].

The supply chain providing these services and the underpinning assets them is diverse, complex and has a number of different structures. These include the basic premise for the provision of a service and the supply of goods (which may have services involved in their creation), where the all tangibility is evident. The supply or creation of goods involves the production and consumption of a tangible asset which may be physical or virtual in its nature, and where a transfer in ownership occurs. Whereas an intangible service describes the tasks performed by individuals for the benefit of others, and there is no transfer of ownership from the services conducted. The built environment and the actions of those using them are a mixture of goods and services. For example, a physical railway line is constructed, rolling stock manufactured and a train service operated for the benefit of the passengers.

[1] Creating Competitive Advantage, Porter, M ISBN 0-7432-6072-2
[2] https://www.ifm.eng.cam.ac.uk/research/dstools/value-chain-/

2.1. Education future themes

By 2040, many of the children born this year will be joining the workforce. The world they find will be very different from ours today. How we work and live is likely to be shaped by artificial intelligence, autonomous vehicles, synthetic biology and many other emerging technologies. Therefore, it is a challenge to anticipate the exact requirements of the built environment to respond to this rapidly changing world. However, the environment which will encourage future learning must be defined if we are to provide the required infrastructure.

The government report on education real estate, building better performance[3] demonstrated that capital investment focussed on spend to enable the curriculum to be delivered in a more effective manner has an impact on attainment. Other investment to the fabric or general condition was shown to have an impact on teacher and pupil morale which, in itself, creates an environment where performance will be enhanced. It also recognises there are many other factors, not least teaching quality, that have a primary statistical influence. This was complemented by a subjective survey[4] of school head teachers that indicted that a third felt their schools were not fit for purpose. This informed the Priority School Building programme[5] which sought to rebuild or refurbish the 537 worse schools around the country.

More recently, research by the RIBA[6] illustrated that with a well-designed and functioning school, a 15% improvement in staff productivity could be attained along with a positive impact on pupil behaviour, engagement, wellbeing and attainment. The research also drew reference to the need to design and build facilities that will be adaptable for the future changes in the way education is delivered and consumed.

Research by the Institute for Education[7] has illustrated that wider societal trends as well as educational reforms will increasingly have implications for school buildings. Procurement methods and capital funding in England are undergoing significant changes which will alter the way in which school building projects are carried out. Sustainability factors will be increasingly taken into consideration when planning design and building of schools. Information and communication technology will affect where, how and what learning takes place in schools and beyond. Many educational futurists are forecasting an increased use of virtual learning environments that will end the endurance of the traditional classroom as the main space for learning, while front-line education professionals recognise in the short term there is still a need for the physical. Schools are expected to adapt in order to become neighbourhood learning centres used by the wider community, as the learning needs of society change. Merely re-furbishing existing stock or creating new buildings in old ways will severely limit the ability of the education system to effectively provide for wider societal changes.

This illustrates that education and the space in which it is conducted will have a relationship and that relationship can be demonstrated to have a causal link. The impact of that causal link in relation to the other factors such as teaching quality attracts some debate in the teaching profession. What is clear is the educational sector will change in the future, this will have an

[3] http://s3.amazonaws.com/zanran_storage/www.dcsf.gov.uk/ContentPages/82174737.pdf
[4] https://schoolleaders.thekeysupport.com
[5] https://www.gov.uk/government/publications/psbp-overview/priority-school-building-programme-overview
[6] https://www.architecture.com/-/media/gathercontent/better-spaces-for-learning/additional-documents/ribabetterspacesforlearningpdf.pdf
[7] https://files.eric.ed.gov/fulltext/ED472377.pdf

economic and societal implication, and the built environment is a contributory factor in creating educational excellence.

The key trends seen in education and the implication on the built environment are summarised in the next section. There is no suggestion made at this stage of the impact or consequence, as this requires further research.

Aging population The population in the UK is aging. In mid-2016, there were 1.6 million people aged 85 years and over (2% of the total population); by mid-2041 this is projected to double to 3.2 million (4% of the population) and by 2066 to treble, by which time there will be 5.1 million people aged 85 years and over making up 7% of the total UK population.[8] This is illustrated in Figure 1. This will result in the need for and outcome that the age of the working population will also increase. This increase in duration in the workforce will create a number of challenges. Particularly with physical work: the ability for sustained work-based activity will diminish over time.

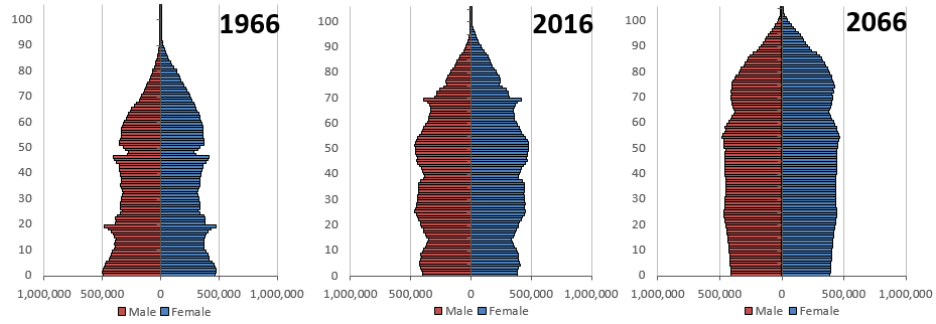

Figure 1 - Population forecast

It is only to be expected that with the change in requirement coupled with the shift in perception of a career, there will be the need for multiple points of education throughout one's lifetime. Many jobs of the future do not exist today, so it is unlikely that education will be able to provide the vocational skills at point of entry to the labour market that will persist through one working life.

Lifelong learning will solve the continuing mismatch between education and the labour market. Educational facilities are expected to offer more customised and problem-solving education and turn into the engaged university.

This changes educational facilities as being the seat of the young with an occasional 'mature student' to a diverse collective who will have differing needs from the educational facility.

Capability development Since the jobs of the future are not all known, and the skills cannot all be taught, the roles of educational institutions will change in society. Alongside the core skills of English, mathematics and science, it is expected new educational programs will form the cornerstones of education[9]. For example, programs that teach cognitive skills such as problem solving or creativity; interpersonal skills such as communication and leadership; and intrapersonal skills, for example, adaptability and discipline. This will help develop critical thinking skills and collaboration in multicultural environments that will provide the basis in which contextual

[8]https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/ageing/articles/livinglongerhowourpopulationischangingandwhyitmatters/2018-08-13

[9] https://observatory.itesm.mx/edu-news/what-will-the-university-be-like-in-2040-georgia-tech

vocational skills can be added as they become applicable to society. The facilities needed to develop capabilities are expected to be different to those needed for traditional skill acquisition.

New educational products Responding to the needs of new capability development will be new educational products and services. It is anticipated that micro-credentials will emerge, where discreet capability or skills can be assessed and added to your digital educational passport. This educational passport is expected to be underpinned by blockchain technology to provide provenance of the qualifications demonstrating learning and achievement credentials to potential employers.

Mindful of the changes in working patterns and flexibility to respond to needs in many other aspects of life, the ability to weave educational needs alongside these other commitments allowing a balance to be obtained will be essential to increasing access to education and the overall capability of the UK to respond to future needs.

Digitalisation The use of digital techniques and products in education is expected to dramatically increase. Online learning and blended learning will increase in education; this will provide access to more information than ever could be imagined, allow the gamification of learning and provide a more immersive educational experience.

Artificial intelligence is expected to be deployed in adaptive learning platforms to provide students with personalised educational experiences based on their learning styles, preferences and needs. This is expected to have a transformational impact on one's ability to learn through a tailored approach and will require the educational facilities to respond to the range of learning styles, approaches and methods.

Distributed education With the advances in digital technologies, a great school, college or university does not need to exist in one single location and can be accessible to anyone in the world [10]. This is anticipated to help with inclusion and access to education for many sections of society that may otherwise be excluded or access impaired.

It will open up opportunities for civic or private spaces to be used as focal points for learning, bringing together diverse sections of local society which will not only create a greater access to knowledge, but will develop friendships and build communities. It is also expected these new centres[11] of learning will engender innovation, entrepreneurship and become key components in the regional socioeconomic ecosystems.

It is not suggested that the traditional seats of learnings will be unnecessary or surplus to requirement, only their role will need to adapt as changes to the traditional models develop.

Considering the major trends for the education sector in the time horizon to 2040-2050, the capability requirements for the UK relevant for CDBB agenda and mandate are summarised in Table 1.

[10] https://www.virgin.com/disruptors/what-will-schools-future-look
[11] http://www.openinnovation.eu/23-01-2017/the-university-in-2040-6-trends-an-infographic/

Table 1 – Education sector capabilities required for CDBB

Theme	National Requirement	CDBB Capability Required
Aging population	• Retraining to align to market labour requirements. • Retraining for contemporary value adding activities aligned to physical ability, desired work patterns and needs. • Lifelong learning.	• Demand and preference driven flexible infrastructure. • Incentivise whole system views of supply and demand. • Commercial structures for whole system (or components within whole system). • Socioeconomic evaluation of infrastructure/service impact and capability.
Capability development	• Developing the ability to learn, problem solve and create. • Developing interpersonal skills of communication, leadership and intrapersonal skills.	• Demand and preference driven flexible infrastructure. • Incentivise whole system views of supply and demand. • Commercial structures for whole system (or components within whole system). • Socioeconomic evaluation of infrastructure/service impact and capability. • Define service outcomes, capability and capacity, linked to the elements of the infrastructure and service required.
New educational products	• Development of micro-credentials. • Creation of digital educational passport. • Flexibility in education provision.	• Demand and preference driven flexible infrastructure. • Incentivise whole system views of supply and demand. • Commercial structures for whole system (or components within whole system). • Socioeconomic evaluation of infrastructure/service impact and capability. • Define service outcomes, capability and capacity, linked to the elements of the infrastructure and service required. • Abstraction of actors to value creation.
Digitalisation	• Greater insight and access to demand data. • Greater insight and access to supply data. • Use of AI to develop tailored services.	• Awareness, training and development in an accessible and consumable form throughout the supply chain and society.

Theme	National Requirement	CDBB Capability Required
	• Digital skills and capability. • Digital access, especially for the vulnerable or excluded. • Availability and access to required data sources. • Definition of integrated data models for asset and service information. • Standards, guidelines and codes of practice for data integration. • Protection of national and personal information.	• Methods developed to present complex information and manage choice to digitally emerging or excluded members of society. • Integration of 'slow' and 'fast' data models. • Standards, guidelines and codes of practice for data integration. • Data privacy and security. • Creation of data models, and the data sources that underpin these systems.
Distributed education	• Online access to education delivery and self-learning. • Creation of mixed-use civic spaces.	• Demand and preference driven flexible infrastructure. • Incentivise whole system views of supply and demand. • Commercial structures for whole system (or components within whole system). • Socioeconomic evaluation of infrastructure/service impact and capability. • Awareness, training and development in an accessible and consumable form throughout the supply chain and society. • Methods developed to present complex information and manage choice to digitally emerging or excluded members of society. • Data privacy and security. • Abstraction of actors to value creation. • Define service outcomes, capability and capacity, linked to the elements of the infrastructure and service required. • Risk, liability and commercial impact for asset information availability, accuracy, integrity, relevance, completeness and timing. • Inclusion of perceptive, subjective and objective criteria into system and business model. • Provision of trusted, secure, and high benefit information to manage choice to digitally emerging or excluded members of society.

2.2. Healthcare future themes

Healthcare is central to all of our lives and in the UK we are privileged to have the National Health Service providing universal care free at the point of use. The Healthcare system is broader than just the NHS, with local authorities and private organisations providing elements of care. The cost of healthcare in the UK, as with all developing countries is soaring. The NHS budget has continued to grow in real terms since its formation and now accounts for the over 30% of the public services budget[12]. This is fuelled by a combination of increasing demand, driven by the aging population and higher expectations, and the cost of supply: providing the care matched to expectations and using new treatments commanding a premium. Hospitals being built today under the Department for Heath guidelines[13] are likely to be around in 2040-2050 and these will need to respond to the changing market needs.

Aging population The population of the UK is aging and this will have a material impact on the healthcare system. The relative spend for patents increases exponentially with age, excluding the value contributed by others in the provision of care of the elderly. As we all get older the illness or disease that would once be fatal can now be treated, thus prolonging life and exposing us to further illness and disease requiring treatment. Healthcare professionals have a desire to keep patients in hospitals for the minimum possible time. This is to create a capacity of beds, prevent exposure to MRSA and alike, and to return the patient home to a familiar environment where convalescence is improved.

The impact on the built environment of an aging population is expected to be a combination of specialist units to administer the ever more specialised treatments and smaller local satellite facilities for basic care provision.

Access to healthcare There is an expectation that face-to-face consultations with a GP will continue to be a principle component of the primary healthcare, but will be augmented by video-consultations from an individual's own home or workplace using a range of technologies, from Smart TVs and mobile phones to virtual reality.

The triage of patients and the use of decision support methods driven by artificial intelligence is a key method of prioritising patients' needs. There is an expectation the use of avatars with synthetic speech and animation will see the creation of virtual GPs. Advances in tactile feedback technology and robotics will potentially allow GPs to conduct a physical examination at a distance, and for practice nurses to provide care remotely.

The primary impact on the built environment of video consultation, AI and tactile feedback will be the need for secure highspeed, high bandwidth communication without white spots across the country. The existing healthcare estate is likely to change, with specialised areas of competence being consolidated and integrated with a network of local facilities that may be multi-use with other private or public sector services.

Digitisation By middle of the century, the data revolution we have long been promised in healthcare will be well established. All sectors of the NHS are expected be fully computerised, with data linkage allowing the creation of personal electronic health records that include all aspects of healthcare. Patients are expected to have full access to their medical records and many

[12] https://www.ifs.org.uk/publications/9186
[13] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/316247/HBN_00-01-2.pdf

will have 'expert systems' that use data from their medical records to support them to lead healthy lifestyles and manage their long-term conditions. Computerised decision-support systems will help ensure that patients receive the most appropriate tailored care. Information governance procedures must keep pace with technology to ensure this open access is not abused and to ensure that they alone are able to access their records[14].

The impact on the built environment of the digitisation will be the need for secure highspeed, high bandwidth communication without white spots across the country. The existing healthcare estate is likely to change, with specialised areas of competence being consolidated and integrated with a network of local facilities that may be multi-use with other private or public sector services.

Precision medicine Genomics[15] will emerge to rapidly gain traction in mainstream medicine and by 2040-2050 whole-genome sequencing to identify disease-causing genes and risk-profiling is expected to available at low cost. It is anticipated every surgery will have a genome reader, able to read a person's genetic make-up. Under strict ethical and privacy conditions, sections of the patient's genetic code could be checked for identified markers. This will enable the GP to determine how effective a medicine will be for that individual and what side-effects are likely to be experienced, enabling the dose to be adjusted or an alternative chosen. GPs will need to find ways of dealing with a range of ethical and societal issues, for instance risk-profiling children for adult-onset genetic conditions, inadvertent disclosure of non-paternity, and employment and insurance discrimination.

Our aging population, coupled with a new generation of novel, personalised pharmacotherapies, will mean that future general practice will have to cope with even greater clinical complexity. Although GPs of the future will be far more familiar with the issue of polypharmacy, they will be helped in their management of patients through automated dose adjustment, based on home monitoring and the availability of custom-made polypills. Drug adverse events will be monitored remotely, with abnormal results interpreted by computer and passed to the GP practice automatically.

It is anticipated diseases such as diabetes, heart and kidney disease will have moved beyond medical therapeutics into a period of 'rejuvenation medicine'. Stem-cell research, genetic engineering and 3D printing will allow patients to have bespoke replacement tissue and organs made, or tailored therapies created onsite. GP practices will incorporate these fabrication functions for a wide range of treatments that can be delivered in the community. It is foreseen the NHS will become able to design and fit increasingly complex structures, such as kidneys, livers and lungs.

The impact on the built environment of precision medicine is the specialist equipment that will be needed as a result. Treatment such as proton therapy requires large, complex, sensitive and high energy equipment to be installed. This will require special consideration in the building design and the local energy systems.

Analytics It is expected new and sensitive monitoring devices, some wearable, some implanted and some built into the home will be continuously measuring physiological and biochemical

[14] https://www.gov.uk/government/publications/the-future-of-healthcare-our-vision-for-digital-data-and-technology-in-health-and-care/the-future-of-healthcare-our-vision-for-digital-data-and-technology-in-health-and-care
[15] http://www.pulsetoday.co.uk/your-practice/2050-gp-/ten-ways-medicine-will-change-by-2050/20009592.article

parameters, observing behaviours and tracking locations. Future wearables will require no conscious input from the patient. Sophisticated algorithms will tailor responses to individual patients based on continuous machine-learning processes, reminding them to take medicines and alerting patients when necessary, nudging them to activity and healthier diet, and encouraging positive thinking.

It is expected that the doctor's surgery or bag will incorporate a miniature portable laboratory that can take immediate measurements of a range of disease and physiological markers, such as basic haematology, biochemistry and immunology tests. This will provide helpful diagnostic data and information about disease severity to improve the safety of care decisions for acutely ill people. This is of particular benefit for elderly patients, who are usually better off being cared for in their home environment, avoiding the distress of an unnecessary attendance at the local hospital assessment unit. There is an increase expected in the use of ultrasound to diagnose and visualise disease. This will pick up the differences between bone, fluid and air, making it suitable for diagnostic work including decision-making.

The impact of improved analytics on the built environment is on one hand that the need for general purpose laboratories at hospitals or specialist facilities will reduce with the advances in wearable/consumables, while, on the other, the need for specialist facilities will increase as new techniques are developed. Integration of secure and trusted highspeed/high bandwidth communications will be required without white spots across the country.

Healthcare business model The UK National Health Service was 70 on the 5th July 2018. The model of universal healthcare where the government both pays and provides is unique. Other countries with universal systems pay with the private sector providing the service, often with patients having the ability to increase their care provision through direct payment or insurance. As discussed earlier the spend on the NHS is considerable and many ask whether this model is sustainable and whether a subscription or use based model will need to be adopted alongside many of our developed country neighbours.

The current NHS target operating model[16] is highly vertically integrated with components of services being supplied by the private sector, but the fundamental primary, secondary, tertiary structure of the healthcare provision has remained unchanged. There is speculation whether this current highly integrated model is offering the best service or providing the best value[17]. The NHS needs to decide what it is: a commissioner of healthcare, healthcare provider, a building operator, a facilities manager or a logistics company.

There is an expectation the staff numbers will reduce in the NHS through a combination of outsourcing, automation, role assignment and diagnostics. It is expected that non-core activities or services will be outsourced to drive efficiency and develop capability. Automation of business processes are expected to increase reducing the number of touch points and manual intervention. Robotics[18] will become a common place for material movement and portering. It is expected that these changes will happen alongside role reassignment to focus nursing assistants on providing care management, and giving trained staff space to focusing on value adding patient interaction, diagnostics, analysis and the implementation of healthcare.

[16] https://assets.kpmg.com/content/dam/kpmg/uk/pdf/2018/09/reimagine-healthcare.pdf
[17] https://doi.org/10.1186/s13054-017-1664-7
[18] https://thejournalofmhealth.com/healthcare-in-2040-how-robots-could-transform-the-nhs/

The siloed healthcare model driven by funding paths is expected to evolve into an integrated healthcare system where an end-to-end patient focused journey is central to the service provision. This will change the focus from the intermittent, reactive sick care to continuous, proactive healthcare in the future[19].

It is expected that the impact on the built environment of the healthcare business model will mean that the current building landscape will need to be shaped to reflect the functions and services offered. The need for such a large fixed use building portfolio, currently 3,500[20], would be expected to change to a more flexible model that can adapt based on demand and focused around the point of use, also releasing capital back to the NHS for reinvestment.

Considering the major trends for the healthcare sector, in the time horizon to 2040-2050, the capability requirements for the UK relevant for CDBB agenda and mandate are summarised in Table 2.

[19] https://www.england.nhs.uk/expo/wp-content/uploads/sites/18/2018/09/10.30-The-NHS-at-100.-a-vision-for-the-future-T2H.pdf
[20] https://www.property.nhs.uk/about-us/

Table 2 – Healthcare sector capabilities required for CDBB

Theme	National Requirement	CDBB Capability Required
Aging population	• Increased routes to healthcare aligned to the spectrum of individual needs. • Increased ability to provide care in the community and home.	• Demand and preference driven flexible infrastructure. • Incentivise whole system views of supply and demand. • Commercial structures for whole system (or components within whole system). • Socioeconomic evaluation of infrastructure/service impact and capability.
Access to healthcare	• Creation of remote consultation services. • Integration of wearable or internal sensors into monitoring and diagnostic healthcare pathway. • Development of decision support systems to increase efficiency and efficacy of diagnostics and assessment. • Personalised treatment and care plans.	• Demand and preference driven flexible infrastructure. • Incentivise whole system views of supply and demand. • Commercial structures for whole system (or components within whole system). • Socioeconomic evaluation of infrastructure/service impact and capability. • Resilience of mission critical infrastructure. • Abstraction of actors to value creation. • Define service outcomes, capability and capacity, linked to the elements of the infrastructure and service required. • Risk, liability and commercial impact for asset information availability, accuracy, integrity, relevance, completeness and timing. • Inclusion of perceptive, subjective and objective criteria into system and business model. • Provision of trusted, secure, high benefit information to manage choice to digitally emerging or excluded members of society.
Digitalisation	• Creation of trusted and secure patients' records systems. • Communications systems secure and resilient for personal and critical information and control.	• Awareness, training and development in an accessible and consumable form throughout the supply chain and society. • Methods developed to present complex information and manage choice to digitally emerging or excluded members of society. • Integration of 'slow' and 'fast' data models.

Theme	National Requirement	CDBB Capability Required
	• Integration of wearable or internal sensors into monitoring and diagnostic healthcare pathway. • Use of automation in treatment, care and support. • Development of decision support systems to increase efficiency and efficacy of diagnostics and assessment. • Personalised treatment and care plans. • Development of digital healthcare ethics.	• Standards, guidelines and codes of practice for data integration. • Data privacy and security. • Resilience of mission critical infrastructure. • Creation of data models, data sources that will underpin these systems.
Precision medicine	• Personalised treatment and care plans. • Communications systems secure and resilient for personal and critical information and control. • Creation of localised on-site manufacture of rejuvenation treatment. • Development of decision support systems to increase efficiency and efficacy of diagnostics and assessment.	• Resilience of mission critical infrastructure. • Data privacy and security.
Analytics	• Integration of wearable or internal sensors into monitoring and diagnostic healthcare pathway. • Development of artificial intelligence and deep learning methods. • Development of decision support systems to increase efficiency and efficacy of diagnostics and assessment.	• Resilience of mission critical infrastructure. • Data privacy and security. • Standards, guidelines and codes of practice for data integration. • Data privacy and security. • Resilience of mission critical infrastructure.
Healthcare business model	• Increased focus on continuous healthcare and reduction in reactive treatment. • Integration of end-to-end healthcare provision. • Development of new healthcare provision models. • Use of automation in treatment, care and support.	• Demand and preference driven flexible infrastructure. • Incentivise whole system views of supply and demand. • Commercial structures for whole system (or components within whole system). • Socioeconomic evaluation of infrastructure/service impact and capability. • Methods developed to present complex information and manage choice to digitally emerging or excluded members of society. • Data privacy and security.

Theme	National Requirement	CDBB Capability Required
		• Resilience of mission critical infrastructure. • Abstraction of actors to value creation. • Define service outcomes, capability and capacity, linked to the elements of the infrastructure and service required.

2.3. Road transport future themes

Transport connects people, businesses and services. It enables people to access schools, jobs, food stores, hospitals and businesses to get their goods to market. But along with economic and population growth comes additional demand for transport.

Passenger transport in the UK recorded the highest volume ever with 801 billion passenger-kilometres and 201 billion tonne-kilometres of domestic freight moved within the UK[21]. Road has been the predominant mode in both passenger and freight transport for over 60 years and urban road freight movements (in van) increased at an average rate of 2% a year for the past five years[22]. The rise in internet shopping and home deliveries is likely to be one of the contributing factors to such a trend.

UK airports handled a total of 268 million terminal passengers and 2.4 million tonnes of freight. Heathrow Airport is one of the busiest airport in the world with 76 million terminal passengers and 481 air transport movements[23].

The Industrial Strategy[24] has described infrastructure as one of the five foundations of productivity. Maintaining and upgrading the transport infrastructure can play a key role in enabling the delivery of the government's plan[25], and the government is already acting on this priority, having allocated over £61 billion in capital investment for transport infrastructure up to 2020/21[26].

The impacts associated to current levels of transport activity are too well known. A multi-departmental report of 2009[27] referred to excess delays having the biggest economic cost of all transport externalities, followed by physical inactivity and the growing level of obesity, road accidents and poor air quality. Currently, it is estimated that congestion costs the UK economy around £31 billion a year, £6 billion in London alone[28]. Moreover, according to official BEIS data[29], transport accounts for the largest proportion of final energy consumption, and has done so since 1988. At around 40% of total energy consumed in the UK, road transport accounted for the largest share of transport consumption, representing 74% of energy consumption in transport in 2016[30] and a quarter of UK domestic greenhouse gas emissions.

Alongside socio-economic and environmental, ongoing changes in the administration of transport infrastructure will present new challenges to the way the infrastructure will be managed and maintained. Notably, the devolution of transport powers, a process that intends to give more control to English local authorities by transferring powers historically centralised to local government, will enable the latter to have more say over strategic transport investment on their local transport network. And, if on one hand, it will enable integration at the local level, for

[21] Department for Transport: *Transport Statistics Great Britain: 2017*
[22] Data computed by the authors from Department for Transport (2017): *Road Traffic Statistics*
[23] Department for Transport: *Transport Statistics Great Britain: 2017*
[24] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/664563/industrial-strategy-white-paper-web-ready-version.pdf [last accessed 11 April 2018]
[25] Department for Transport (2017): *Transport Investment Strategy*
[26] Department for Transport (2017): *Proposals for the Creation of a Major Road Network Consultation*
[27] Cabinet Office et al: *The wider costs of transport in English urban areas 2009*
[28] INRIX: *INRIX 2016 Traffic Scorecard – U.K.;* http://inrix.com/resources/inrix-2016-traffic-scorecard-uk/ [last accessed 28 March 2018]
[29] Department for Transport: *Transport Statistics Great Britain: 2017*
[30] Data computed by the authors from Department for Business, Energy & Industrial Strategy: *Energy Consumption in the UK* (2017)

instance through smart ticketing, the risk is that this decentralisation will hinder an integrated approach to infrastructure and data management at a network level.

Given the increasing pressure on existing transport networks as a consequence of the additional demand for transport that comes from economic and population growth, it is of utmost importance to understand how to achieve higher levels of performance of the existing and future transport infrastructure.

As society evolves, human kind responds and mitigates the damage inflicted on the planet, and economies develop around the world, the transport needs for the UK in 2050 continue to change. The UK population is predicted to grow from 64 million to 77 million by 2050[31]. A greater proportion of these people will live in cities and the over-65 population is expected to almost double. This will increase pressure on existing transport infrastructure and create additional mobility needs. The economics of society will change. The emerging markets and developing countries now account for more than half of global economic growth. This is increasing their demand for resources and also affects global trade patterns. The trends in behavioural patterns among young adults (18-34 years) continue to evolve. These include higher participation in further education and a delay in marriage and traditional household formation. As the global climate continues to change, the UK is expected to see increasingly unpredictable weather with more extreme events. This will continue to exercise the resilience of the UK's transport infrastructure. The major themes identified for the surface transport sector are:

Reduction in air pollution Ambient (outdoor air pollution) is a major cause of death and disease globally. The health effects range from increased hospital admissions and emergency room visits, to increased risk of premature death. An estimated 4.2 million premature deaths globally are linked to ambient air pollution, mainly from heart disease, stroke, chronic obstructive pulmonary disease, lung cancer, and acute respiratory infections in children.

Pollutants with the strongest evidence for public health concern, include particulate matter (PM), ozone (O_3), nitrogen dioxide (NO_2) and sulphur dioxide (SO_2). The health risks associated with particulate matter of less than 10 and 2.5 microns in diameter (PM10 and PM2.5) are especially well documented. PM is capable of penetrating deep into lung passageways and entering the bloodstream causing cardiovascular, cerebrovascular and respiratory impacts. This has been classified as a cause of lung cancer by the World Health Organisation's (WHO) International Agency for Research on Cancer (IARC). It is also the most widely used indicator to assess the health effects from exposure to ambient air pollution[32].

To mitigate the creation of these pollutants, the transportation sector will reduce the number of internal combustion engine powered vehicles and move to electric. These produce zero emissions directly, although they may cause indirect emissions through the electricity they use, during generation, or their manufacturing process. The UK Government announced the end of the sale of all new conventional petrol and diesel cars and vans by 2040 in its UK plan for tackling roadside nitrogen dioxide concentrations[33]. This has a large impact on the transport and energy sectors from all aspects. There is an anticipated 34 million Electric Vehicles (EV) on the road requiring

[31] https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates
[32] https://www.who.int/airpollution/ambient/health-impacts/en/
[33] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/633270/air-quality-plan-detail.pdf

60TWh of electricity per year by 2040. Dependant on the method of electricity generation it will also have an impact on the decarbonisation of the transportation sector.

Decarbonisation Transportation is responsible for 14% of greenhouse gas emissions globally[34]. In order to achieve the Paris Agreement[35], decarbonisation of the transport sector will be essential. The main levers to be exercised in decarbonisation are[36]:

Electrification The reduction in the carbon produced to transport people and goods through the use of electric vehicles. This also addresses the road side air pollution challenge described earlier. The increase in electrification will require the infrastructure to support the vehicle charging. It is forecast the majority of private vehicles will be slow charged overnight at home, while an increase in mobility-as-a-service and the higher vehicle usage will require faster distributed charging networks around centres of urban and sub-urban density. For commercial use, whether this is cars, vans or trucks, there is a need to have a wider extra-urban network to enable greater distances to be travelled with confidence.

Demand reduction The reduction in demand, through changes in patterns of behaviour or an increase of density in people and goods. This is explored in further detail later in this section.

Modal shift Switching to transport modes that are inherently more carbon efficient than others. This includes moving from private to public transport, using high speed rail rather than air for medium distance journeys, and the use of cycles and walking to cover short distances.

Changes in demand There is an ever-increasing shift of populations to cities and large towns. This is driven by a combination of employment opportunity, access to services and leisure options[37]. This is being seen for both young adults attracted by opportunity and the old driven by the access to services. However, this desire to be located in the centres of conurbation is tempered by affordability which impacts travel patterns especially for families who tend to move to suburban areas. Over the past twenty years, the distance that people commute to work has increased slightly. However, there has also been a decrease in the number of commuter trips made. This combination of fewer, but longer commutes is likely due to several factors, including more opportunities to work from home and increasing suburban house prices which force commuters further from city centres.

The proportion of jobs located in city centres continues to rise as the number of jobs in knowledge-based industries typically located in or near city centres increases[38]. This is process is called 'agglomeration'[39]. Agglomeration economies or external economies of scale refer to the benefits from concentrating output and housing in particular areas. If an area specialises in the production of a certain type of good, all firms can benefit from various factors such as: good supply networks, supply of trained workers, infrastructure built specifically for the industry and good transport links. Due to agglomeration economies, people and firms often concentrate in particular areas. For example, people tend to move to cities where is there is a greater choice of jobs, social activities and specialist services. This increases demand on public transport both in and to/from

[34] https://wriorg.s3.amazonaws.com/s3fs-public/resources/world_greenhouse_gas_emissions_flowchart.pdf?_ga=2.151633145.1379760340.1542995307-739773925.1542995307
[35] https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement
[36] https://ec.europa.eu/transport/sites/transport/files/themes/strategies/doc/2001_white_paper/lb_com_2001_0370_en.pdf
[37] https://www.weforum.org/agenda/2018/10/this-is-why-people-live-work-stay-leave-in-growing-city/
[38] https://www.centreforcities.org/blog/why-do-businesses-flock-to-certain-areas-of-britain/
[39] https://dictionary.cambridge.org/dictionary/english/agglomeration

cities. Without using levers like road user charging and low emissions zones, if public transport is not a viable or preferred option, there is a risk of increasing congestion on the roads. Furthermore, once the vehicle is within the urban space it needs to be parked, which increases competition for land for car parking[40].

Mobility-as-a-Service There is a recognition that personal transportation is an unsustainable, but often necessary, extravagance. As the trend continues away from an ownership to a service culture, the need to own your means of transport will diminish. An analysis of the maturity and performance of mobility systems has shown that, due to the complex nature of the problems at hand, separate optimisation at sub-system level has strong limitations, and only system-level improvement will significantly improve overall mobility performance. However, in most of today's mobility systems, means of transportation are often still divided, and public and private stakeholders do not work together sufficiently closely on the development of seamless and networked mobility ecosystems.

The concept of 'Mobility-as-a-Service' (MaaS) aims to provide consumers with integrated, flexible, efficient and user-oriented mobility services. It implies a shift away from the personal ownership of individual motorized transportation modes, and non-integrated means of transportation towards the use of integrated multimodal mobility solutions consumed as services. This shift is enabled by combining transportation services from public- and private-transportation providers through an 'integrated mobility platform' that creates and manages the journey and integrates planning and payment (based on mobility packages tailored to the needs of each customer segment) on a one-stop-shop principle.

The high expectations of the concept of MaaS are fuelled by the anticipated evolution from ownership of a personal car towards consuming mobility through a combination of on-demand mobility services. These are expected to become significantly more affordable once autonomous vehicles are widely available. Until recently, while the concept of MaaS has been largely applied to individual mobility, it can be applied for the same reasons to the movement of goods.

Well-integrated physical multimodal mobility infrastructures and solutions are a prerequisite to a well-functioning MaaS concept. This requires long-term alignment between mobility stakeholders on a shared mobility vision and strategy, and a coordinated approach to investments. The development and implementation of a multi-modal transport master plan, ensuring the optimal allocation of transport modes in space and in time, will benefit the system as a whole.

At the core of MaaS is the integrated mobility platform and application(s). These will allow for the creation and management of journeys and act as the user-interface with consumers, along with the tariff model which includes the service governance and risk sharing. This is of particular relevance when the model is evolving, where the likelihood of a misalignment between revenue and return is high, and where the commitment by the service provider is significant.

The public transport authorities are key stakeholders and actors in the enablement of the MaaS concept at city, regional or national level, and the following conditions are anticipated to be necessary:

[40] https://phys.org/news/2018-01-cities-dominance-space.html

- Defining integrated and multimodal mobility plans and making arbitrage for investment in public- and road-transport infrastructures.
- Providing, through regulation, access conditions and guidelines for new mobility solutions providers, which have a critical role to play in the implementation of MaaS.
- Defining the rules of the game in terms of an open-data policy for public transport and the provision of access to the Application Programming Interface (API) required for the development of back-end platforms.
- Establishing the right governance mechanisms to ensure MaaS operators strive for the best system possible, allowing optimisation of the mobility system as a whole by taking an agnostic approach to different transport modes.

The mobility solutions providers, such as train, bus, car share, taxi, bike share, parking, active travel and autonomous vehicles (discussed in next section) also have a critical role to play as increased convergence between providers (both public and private) is critical to enable gradual evolution towards Mobility-as-a-Service. The key areas are:

- Contributing to the development of integrated and multimodal mobility visions and an integrated transport master plan.
- Collaborating with other solutions providers to better manage relevant mobility data as an input for the defining of mobility offerings in-line with mobility demand, and contributing along with public transport authorities to creating and enacting a data policy and information exchange agreements.
- Creating an ecosystem for innovation and inclusion by taking a leading role or participating as a third party in the development and implementation of integrated mobility platforms and applications.

Connected and Autonomous Vehicles The forecasts for the number of connected and autonomous vehicles on our road varies considerably depending on the study and the optimism. What is evident is that they are coming, and this will impact our existing mobility services and infrastructure. This level of market penetration ranges from 10-15% of all vehicles sold by 2035, dependant on the level of automation deployed, and based on a median forecast.

The functionality provided by the level of connection and autonomy ranges from providing traffic updates at the elementary level through to making operational assistance. The SAE[41] defined six levels of connection and automation: this illustrates the adjacency of connected and autonomous vehicles along with the differing levels of control that is exercised. The use case for each of the levels of connectivity and automation are included in Table 3:

[41] https://www.sae.org/misc/pdfs/automated_driving.pdf

Table 3 - Use cases for different levels of autonomous control

No automation	1 Driver assistance	2 Partial automation	3 Conditional automation	4 High automation	5 Full automation
Human driver performs part or all of the dynamic driving task; in particular, the driver is responsible for monitoring the environment and any action taken by the automation system			System performs entire dynamic driving task while engaged, including monitoring and response, as well as steering and acceleration		
Human driver performs all aspects of dynamic driving tasks	System can perform either steering or acceleration	System can perform both steering and acceleration	Human driver may be requested to intervene (fallback)	Full automation in some driving modes	Full automation in all driving modes
e.g. Park Assist, Adaptive Cruise Control	e.g. Traffic Jam Assist		e.g. Intersection Pilot, Platooning	e.g. Urban automated driving	

It is expected that the majority of connected and autonomous vehicles (CAV) systems will need a combination of detailed mapping of the road network and real-time information received from sensors to safely navigate the road network. This presents a series of considerations for the future infrastructure requirements. A study for the Department of Transport about future proofing infrastructure for connected and autonomous vehicles[42] identified the following categories as areas for further consideration:

Traffic Management Measures Roadworks may alter the road layout, changing where vehicles are expected to travel. For human drivers, intuition and ability to interpret road signs allows them to navigate these areas. However, CAVs may not have the intelligence to interpret a new environment correctly, and therefore may have difficulty navigating through these areas. Due to these difficulties, consideration needs to be given to future design, implementation, and the operation of traffic management measures. This includes planned and unplanned roadworks. Planned roadworks might be scheduled weeks or months in advance and information about their design and implementation could be foreseen and included in the network model through close cooperation between contractors and local authorities. However, emergency roadworks, including broken-down vehicles in the carriageway, occur on an ad-hoc basis and cones are placed on the carriageway by the first responders to the scene. This will require special consideration within the network model, sending alerts via the infrastructure to vehicle systems, and transmitting them to the CAVs to adopt the appropriate control.

Road markings In addition to the detailed network maps, a number of CAV technologies rely on situational awareness from the road markings for guidance. These include lane markings and other on-road indication such as stop lines or signage. The challenges that need to be addressed to enable CAVs to tackle road markings include: old road markings not completely obscured even if blacked out, bitumen lines used to seal cabling or drainage in the roadway, faded indistinct lines on asphalt surfaces, slightly faded lines on concrete road surfaces which present poor contrast, lane markings not in normal use, and discontinuous markings. While road signage is not safety critical and the information contained within should be part of the detailed network model, any control systems relying on this infrastructure for visual information will be impaired. Inclement weather such as rain, fog and snow may also impair the visibility of marking, as will direct sunlight, causing saturation of sensors.

[42] https://s3-eu-west-1.amazonaws.com/media.ts.catapult/wp-content/uploads/2017/04/25115313/ATS40-Future-Proofing-Infrastructure-for-CAVs.pdf

For the safe operation of CAVs, the quality of the road surface and marking will need to be improved and maintained, with alerts to the operational teams to remedy degradation captured through a series of sensors in the surface and LiDAR imagery captured to condition monitoring. The roadside infrastructure will need to be able to visually interpret the situation in order to send set transmission messages, providing real-time information to the CAV through a series of beacons throughout the network.

Safe harbour areas It is likely that in full autonomy, the driver vehicles will be travelling at speed with the driver disengaged from driving the vehicle with no awareness of the situation. It is also possible the driver may not be in a fit condition to take control of the vehicle before a planned exit point due to an incident ahead, CAV vehicle malfunction, inclement conditions or if the driver is incapacitated. Here the CAV will need to find a safe harbour ready for conditions to revert to a state where automatic running can resume, or where manual control can be taken. This is analogous to the emergency refuge areas seen on the Smart Motorway network or exiting the network at the next departure point and resting at a suitable location such as a service station.

Service stations will provide off-network high-capacity safe harbours, locations for charging electric vehicles and mode interchange locations within the network. It is anticipated that the majority of CAV will be electric vehicles and a proportion of these vehicles will be used for distances greater than the capacity of a single charge, therefore requiring replenishment at rapid charging points. The mode interchange is of particular relevance when the CAV is being used as part of a MaaS network, where there is a pool of CAVs for use on routes not served by public or mass transit.

Car parking Whether the CAVs are private and shared, there are locations where the vehicles will need to reside. The benefit of CAV is the space required between vehicles for access and egress is significantly less as the driver and passengers do not need the space. In addition, techniques adopted from the logistics sector can be adopted to shuffle vehicles to enable access. This enables the existing car parks to have increased capacity and reduce the size of new car parks for the same number of vehicles.

Automated Demand Response Public Transport It is anticipated that the modes within the MaaS system will include lower capacity automated demand response public transport, or autonomous taxis or mini-buses to provide network in-fill or point-to-point solutions. These enable new services to be provided and optimised as demand/supply routings are determined.

Crossings and junctions are a key feature of our road networks, especially urban and suburban. These include pedestrian crossings such as uncontrolled, zebra or signalled; junctions, which are marked, signalled (operational or in a failure state), or priority controlled; and level crossings. Non-signalised junctions may prove to be challenging for CAVs and it is anticipated that a greater number of signalised junctions will be needed. These signalised junctions, like other visual indicators like road signage, will require infrastructure to vehicle and vehicle to infrastructure communication to inform the network of classification, priority, presence and destination, along with the network communicating instructions to manage localised demand. It is foreseen that a significant development of the CAV's visual analytics will be required if CAVs are permitted to operate in areas where other road users will be

present. The network resilience will be highly dependent on the performance of these crossings and junctions. This will increase the need for sensing the performance of infrastructure and monitoring the operational spaces.

Impact on bridge structures Bridges are features of significant importance within the network, unlocking social progression and economic growth when built. The design guidelines for bridges in the UK are described in the Design Manual for Bridges and Roads[43]. This assumes that the lorries are dispersed along the route and interspersed with cars and light vehicles. Platooning of CAV lorries is a popular use case that will reduce fuel economy and increase network capacity. Alongside control logic to disperse lorries crossing a bridge, the bridge loading will need monitoring to ensure design parameters are not exceeded and any degradation closely monitored.

Digitisation of sector The actions identified to address air pollution and reduce the level of carbon from transport, along with new services like MaaS and CAV all rely on data and information to provide that service. The impact on infrastructure from these advancements require information about the asset's usage and performance to inform the planning process, which in turn are described in the design and subsequently realised through construction. The asset usage and performance are an essential element of feedback that will assist in the predictive maintenance and, where necessary, rapid diagnostic in the event of an incident, essential to maintain high levels of availability.

The information used for transportation will need to be handled in accordance with the relevant data privacy regulation, as it will be possible to derive considerable insight into individual patterns of behaviour. With the increased dependency on a tightly coupled system, the security classification of the network and nodes within will require evaluation to ensure the appropriate oversight and governance is in place. The resilience of the network and the services they depend on (either directly or indirectly) will need evaluation to ensure neither assets, services, nor the beneficiaries of the services are stranded.

Closer coupling of sector with infrastructure providers The transport sector itself will become more closely coupled. This increases the number of touch-points or adjacencies with other infrastructure providers.

The transportation sector will become more closely coupled with the energy sector as the reliance on electricity as a power source increases. This will require the management of supply and demand to be considered across the traditional sectoral boundaries. Potential will be unlocked as the quantity of electricity storage (with on-board batteries) will increase dramatically, while needing careful management to ensure demand requests are balanced. The respective system operators of the energy networks and transport networks will therefore be required to collaborate in new methods of working and the development of new agreements.

Both the transportation and the energy sector will individually and collectively need to serve the housing needs that will develop. The shortfall in housing will continue to be addressed with new developments in accordance with the housing strategy. This will put additional demands on the

[43] http://www.standardsforhighways.co.uk/ha/standards/dmrb/

already stretched sections of the networks in terms of capacity, but also to create linkages so that communities are formed rather than dormitory towns..

The capability requirements for the UK relevant for the CDBB agenda and mandate are summarised in Table 4. These consider the major trends for the road transport sector in the time horizon 2040-2050.

Table 4 - Road transport capabilities required for CDBB

Theme	National Requirement	CDBB Capability Required
Reduction in air pollution	• Electrification of vehicles. • Creation of clean air zones.	• Methods to trigger and reward behavioural change. • Incentivise whole system views of supply and demand. • Creation of relationships between provision, benefit, costs, risk and reward. • Commercial structures for whole system (or components within whole system). • Socioeconomic evaluation of infrastructure/service impact and capability. • Creation of relationships between provision, benefit, costs, risk and reward.
Decarbonisation	• Electrification of vehicles. • Reduce demand. • Modal shift to low carbon solutions.	• Methods to trigger and reward behavioural change. • Incentivise whole system views of supply and demand. • Creation of relationships between provision, benefit, costs, risk and reward. • Commercial structures for whole system (or components within whole system). • Socioeconomic evaluation of infrastructure/service impact and capability.
Changes in demand	• Increased demand for public transport capacity in urban areas. • Increased demand for public transport transit time capability in suburban/extra-urban areas.	• Methods to trigger and reward behavioural change. • Incentivise whole system views of supply and demand. • Commercial structures for whole system (or components within whole system). • Socioeconomic evaluation of infrastructure/service impact and capability.
Mobility-as-a-Service	• Physical integration of transport modes. • Schedule integration of transport modes, including demand regulated. • Digital integration of transport modes. • Increased surety and resilience in service provision. • Creation of new services. • Creation of new service platforms.	• Abstraction of actors to value creation. • Incentivise whole system views of supply and demand integrated platform. • Infrastructure use/value-derived and charging model based on demand, environmental conditions and affordability. • Supply chain realignment based on value and creation of value chains. • Creation of trusted value chain to warrant the commercially relevant transfer of information (or other outcome). • Creation of the data models and data sources that will underpin these systems. • Define service outcomes, capability and capacity, linked to the elements of the infrastructure and service required.

Theme	National Requirement	CDBB Capability Required
		• Risk, liability and commercial impact for asset information availability, accuracy, integrity, relevance, completeness and timing. • Inclusion of perceptive, subjective and objective criteria into system and business model. • Provision of trusted, secure, high benefit information to manage choice to digitally emerging or excluded members of society.
Connected and Autonomous vehicles	• Vehicular automation technology. • Improvements in road and road-side infrastructure to facilitate CAV. • Managing ad-hoc events and emergencies. • Modal shift to CAV. • Integration into MaaS.	• Outcome-based contracting for infrastructure. Determination of ongoing asset condition for the suitability of CAV operation. • Define service outcomes, capability and capacity, linked to the elements of the infrastructure and service required. • Risk, liability and commercial impact for asset information availability, accuracy, integrity, relevance, completeness and timing. • Inclusion of perceptive, subjective & objective criteria into system/business model.
Digitisation	• Digital skills and capability. • Digital access, especially for the vulnerable or excluded. • Availability and access to required data sources. • Definition of integrated data models for asset and service information. • Standards, guidelines and codes of practice for data integration. • Protection of national and personal information.	• Awareness, training and development in an accessible and consumable form throughout the supply chain and society. • Creation of trusted value chain to warrant the commercially relevant transfer of information (or other outcome). • Methods to be developed to present complex information and manage choice to digitally emerging or excluded members of society. • Integration of 'slow' and 'fast' commercial and data models. • Standards, guidelines and codes of practice for data integration. • Data privacy and security.
Closer coupling of sector with infrastructure providers	• Integrated system modelling at varying levels of geographical focus and with focus on service outcomes. • Inclusion of perceptive, subjective and objective criteria into system model. • Understand the impact of system disturbances.	• Integrated system business model. • Risk, liability and commercial impact for asset information availability, accuracy, integrity, relevance, completeness and timing. • Methods to increase surety and resilience in complex systems • Data privacy and security.

2.4. Energy future themes

The global energy system remained unchanged from its inception for many years and consists of a hierarchical and linear system of central generation, high voltage transmission to regions, and distribution to medium/low voltage consumers. The introduction of renewables at various points in the existing system increased the decentralisation of network and the term smart grid was born.

Today we are on the cusp of major changes to this traditional sector provoked by a combination of customer demand, technological enablement, network upgrade and the economic balance of the current model. Exactly what this future will look like and when, is a subject of considerable discussion in the sector, but what is clear is the direction of travel. This is subject to opposing forces in places, and will be unpacked in this section. The major themes identified are:

Changes in demand In the Evolving Transition scenario, which assumes that government policies, technologies and societal preferences evolve in a manner and speed similar to the recent past, world GDP more than doubles by 2040, driven by increasing prosperity in fast-growing emerging economies, as more than 2.5 billion people are lifted from low incomes. This rising prosperity drives an increase in global energy demand, although the extent of this growth is offset by accelerating gains in energy efficiency: energy demand increases by only around one third over the next 25 years[44].

The decrease is a function of forecast improvements. Energy efficiency is a key feature in the observed trend of the energy transition. The world's energy intensity, the units of energy per unit of GDP, has been declining by, on average, 1.1% per year for the last two decades. This is anticipated to increase to an average annual decrease of 2.3% due to the accelerating electrification of the energy system which is more efficient than fossil fuels.

This situation is accentuated by more solar PV and wind generation capacity being installed, with only negligible energy losses. This efficiency trend will be further boosted by Electric Vehicles becoming mainstream in automotive markets, as they consume about a quarter of the energy used by Internal Combustion Engine Vehicles. In addition to this, the annual energy efficiency improvement in the road sector is boosted by strong electrification, to 3.4% per year over the forecast period.

The other transport sub-sectors, and the building and manufacturing sector, will electrify more slowly than the road sector; hence they will not experience a similar additional boost in energy efficiency. Nevertheless, the average annual energy efficiency improvements vary between 0.9 and 2.0% per year for these sectors as well.

Decarbonisation The historic energy mix has been a significant contributor to climate change. The replacement of fossil fuel generation with renewable energy is beginning to make an impact with around 30% of installed capacity[45]. Reduction in consumption per capita continues to reduce and the change to low carbon vectors all help. Yet more is required if the targets of the Paris agreement are to be achieved.

The world's energy system is expected to decarbonise, with the 2050 primary energy mix split equally between fossil and non-fossil sources. Oil demand will peak in the 2020s and natural gas

[44] https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/energy-outlook/bp-energy-outlook-2018.pdf
[45] http://fes.nationalgrid.com/media/1363/fes-interactive-version-final.pdf

is expected to take over as the biggest energy source in 2026. Existing fields will deplete at a faster rate than the decrease in oil demand. New oil fields will be required through to 2040.

Environmental legislation has been an important driver in reducing the UK's carbon emissions. The UK is currently committed to a number of environmental targets, particularly the Climate Change Act 2008[46]. This is the UK contribution to the Paris Agreement that seeks to hold the increase in global temperatures to less than 2˚C above pre-industrial levels.

The Climate Change Act legally binds the UK to reduce carbon emissions by at least 80% from 1990 levels by 2050, (the '2050 carbon reduction target') via a series of carbon budgets. This is underpinned by further legislation and policy measures. Many of these have been consolidated in the UK Clean Growth Strategy[47].

The European Union's 2030 Climate and Energy Framework[48] also includes a number of decarbonisation targets for 2030, namely:

- At least a 40% reduction in greenhouse gas emissions (from 1990 levels).
- Renewable energy to make up at least 27% of energy consumption in the EU.
- Energy efficiency – reducing energy use by at least 27% (when compared to the projected use of energy in 2030).

The EU 2030 targets will continue to be binding on all EU member states. Although the UK's future relationship with the EU is yet to be determined (and not anticipated to change at the point of writing), the UK's current energy and climate policy is in line with the EU's 2030 targets, and in some cases is more ambitious.

Decentralisation Generating closer to the point of use not only increases overall resilience, it reduces the large capital costs of central generation and transmission by having smaller scale production and storage closer to the point of consumption. This is, in itself, more efficient. The flexibility improves as the methods deployed in the energy value chain can be optimised to local conditions and profiles.

The point when the amount of decentralised energy production exceeds centrally grid-delivered energy is in the near future. It is forecast that off-grid energy will reach cost and performance parity with grid-delivered energy as early as 2021 in Oceania, dominated by solar energy. Whereas, it is anticipated that the cost of transporting electricity exceeding the cost of generating and storing it locally will occur in the US Northeast region first in 2039.

Digitisation is expected to have a major impact on the secto with power systems becoming more connected, intelligent, efficient and reliable. Smart Grids are already improving the safety, productivity, accessibility and sustainability of the power systems, enabling supply and demand to be more closely matched. The introduction of more analytics and intelligence into the value chain is expected to yield further benefits, enabling new business models and services to be developed.

Digitisation has and will continue to lower the cost of monitoring and control of all methods of energy generation. In transmission and distribution networks, it is expected improve efficiency

[46] https://www.legislation.gov.uk/ukpga/2008/27/contents
[47] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/700496/clean-growth-strategy-correction-april-2018.pdf
[48] https://ec.europa.eu/clima/policies/strategies/2030_en

and lower losses by operating closer to the optimum conditions. In asset intensive value chains, the insight surfaced through digitisation will drive improvements in planning, predictive maintenance and operations.

In the power sector, digitisation is an important enabler of the energy transition that is upon us. Smart Metering and demand response will provide a better way of matching demand with supply. This will help manage the intermittency and variability that is increasing with the higher levels of renewable sources in our energy mix. It is anticipated this improved level of control will contribute to a 4% reduction in the peak load capacity, reducing the need to build expensive energy generation capacity around the globe.

The greater adoption of digitisation in itself will increase the energy required to operate the digital devices, albeit the impact is negligible compared to other dominant sources.

From a customer perspective, it enables the personalisation of a service based on preferences and choice. As a focus on the outcome or output is created, this has the potential to change the relationship between the individual and energy.

Customer experience The customer experience of the energy sector is not at the same level as other services, with examples such as ScottishPower being fined by Ofgem for poor service hitting the headlines[49]. The Competitions and Markets Authority[50] issued a report into the state of the market that concluded there are low levels of customer service provided, and the level of trust with consumers and the level of choice is limited. The level of vertical integration within the sector from generation to supply may be a factor in the organisations having a culture of the heavy engineering and complex market economics at the core, rather than a true customer focus. This is at a time when the level of engagement with the service is reducing and yet the appetite of the consumer to make a change is not high.

As market deregulation continues which will allow new service providers to enter the market, there is an expectation of changes analogous to the telecoms market to emerge. Here there is a clear and growing distinction from the infrastructure and the service as the market matures. While there are still pockets of mobile 'black spots' generally, coverage intricately linked to the infrastructure is no longer a point of differentiation. The energy sector is more mature than the telecoms sector and the regulation preventing this decoupling are anticipated to change.

This change will enable organisations to emerge and develop using the other dominant trends in the market such as information and enabling technology to create new offerings and services. While the details of the services are yet to emerge, and many are speculating about what they may be, these include[51] the concept of Energy-as-a-Service. Energy consumers do not value a kWh of electricity or a BTU of gas. They value the warmth that it provides, or the light that it enables. That is why energy-as-a-service models are starting to appear where consumers might buy warmth, lighting and power rather than units of electricity and gas. The service would be provided by a business that competes for customers by delivering that warmth, lighting and power most efficiently – perhaps by helping improve home insulation, supplying the best equipment to deliver the required service, sourcing the best energy supplies and optimising any local generation or storage. Traditionally, consumers have purchased their energy from one of the big six energy

[49] https://www.ofgem.gov.uk/publications-and-updates/scottishpower-pay-18m-customer-service-failings
[50] https://www.ofgem.gov.uk/sites/default/files/docs/2014/03/assessment_document_published_1.pdf
[51] https://innovateuk.blog.gov.uk/2018/03/06/predictions-the-future-of-energy/

suppliers yet, with the rise of microgeneration, people will generate their own power and sell it back to the grid enabling everyone to be their own energy supplier.

Electrification of transportation The UK Government recently announced in its UK plan for tackling roadside nitrogen dioxide concentrations[52], to end the sale of all new conventional petrol and diesel cars and vans by 2040. This has a large impact on the transport and energy sectors from all aspects. There is an anticipated 34 million Electric Vehicles (EV) on the road requiring 60TWh of electricity per year.

Ofgem reported on the implication of the transition to electric vehicles[53] and stated that the impact of EV on the electricity network is not as simple as substitution of petrol or diesel vehicle for an EV, as our relationship with the mobility is expected to change in the coming generations. This is detailed in the previous sections. What is clear is a network is required that allows for the charging of a variety of vehicles, including those that are private owned and charged at home, the majority using an overnight slow charge. An increase in mobility-as-as-service will require rapid charging around the city and regions if these vehicles are not to be stranded. In addition, commercial use, whether this is car, van or truck, will need locations across the network where rapid charging of large numbers of vehicles is possible.

This EV demand is anticipated to impact the distribution network the greatest, through the overall increased capacity of high demand consumption at a local level and the impact of the control logic used to determine the best price to charge the EV. The latter point will need integration of the capability and capacity of the electricity network, with the new services delivered for electricity provision and charging to ensure unintended consequences of power demand spikes do not occur.

The capability requirements for the UK relevant for CDBB agenda and mandate are summarised in Table 5. These consider the major trends for the energy sector, in the time horizon to 2040-2050.

[52] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/633270/air-quality-plan-detail.pdf
[53] https://www.ofgem.gov.uk/ofgem-publications/136142

Table 5 – Energy sector capabilities required for CDBB

Theme	National Requirement	CDBB Capability Required
Changes in demand	• Long term reduction in overall demand driven by efficiency, with short term increase driven by growth. • Greater contribution of renewable energy. • Methods for improving the relationship and consideration of energy.	• Methods to trigger and reward behavioural change. • Incentivise whole system views of supply and demand. • Commercial structures for whole system (or components within whole system). • Socioeconomic evaluation of infrastructure/service impact and capability.
Decarbonisation	• Reduced reliance on fossil fuels and transition to renewables. • Electrification of vehicles, heat and processes. • Long term reduction in overall demand driven by efficiency and behavioural change.	• Methods to trigger and reward behavioural change. • Incentivise whole system views of supply and demand. • Creation of relationships between provision, benefit, costs, risk and reward. • Commercial structures for whole system (or components within whole system). • Socioeconomic evaluation of infrastructure/service impact and capability.
Decentralisation	• Higher levels of generation closer to the point of use. • Balancing supply and demand at national and local levels. • Greater insight and access to demand data. • Control of demand. • New business models to decouple infrastructure and service provision. • Integrated system modelling at varying levels of geographical focus and with focus on service outcomes. • Understand the impact of system disturbances.	• Data privacy and security. • Methods to trigger and reward behavioural change. • Incentivise whole system views of supply and demand. • Integrated platform. • Infrastructure use/value-derived and charging model based on demand, environmental conditions and affordability. • Supply chain realignment based on value and creation of value chains. • Creation of trusted value chain to warrant the commercially relevant transfer of information (or other outcome). • Creation of the data models and data sources that will underpin these systems. • Risk, liability and commercial impact for asset information availability, accuracy, integrity, relevance, completeness and timing.

Theme	National Requirement	CDBB Capability Required
		• Inclusion of perceptive, subjective and objective criteria into system and business model.
Digitisation	• Greater insight and access to demand data. • Greater insight and access to supply data. • Digital skills and capability. • Digital access, especially for the vulnerable or excluded. • Availability and access to required data sources. • Definition of integrated data models for asset and service information. • Standards, guidelines and codes of practice for data integration. • Protection of national and personal information.	• Awareness, training and development in an accessible and consumable form throughout the supply chain and society. • Methods to present complex information and manage choice to digitally emerging or excluded members of society. • Integration of 'slow' and 'fast' data models. • Standards, guidelines and codes of practice for data integration. • Data privacy and security. • Creation of the data models and data sources that will underpin these systems.
Customer experience	• Improved customer experience. • Change of relationship with energy to enabled outcomes. • New business models to decouple infrastructure and service provision. • Inclusion of perceptive, subjective and objective criteria into system model. • Greater insight and access to demand data. • Greater insight and access to supply data.	• Data privacy and security. • Abstraction of actors to value creation. • Methods to trigger and reward behavioural change. • Incentivise whole system views of supply and demand. • Supply chain realignment based on value and creation of value chains. • Define service outcomes, capability and capacity, linked to the elements of the infrastructure and service required. • Risk, liability and commercial impact for asset information availability, accuracy, integrity, relevance, completeness and timing. • Inclusion of perceptive, subjective and objective criteria into system and business model. • Provision of trusted, secure, high benefit information to manage choice to digitally emerging or excluded members of society.
Electrification of transport	• An extra 60TWh of demand for EV. • Charging infrastructure.	• Methods to trigger and reward behavioural change. • Incentivise whole system views of supply and demand.

Theme	National Requirement	CDBB Capability Required
	• Integration of EV batteries into national and local energy vectors. • New transport services, such as MaaS.	• Commercial structures for whole system (or components within whole system). • Socioeconomic evaluation of infrastructure/service impact and capability.

2.5. Future capabilities required for CDBB

The capabilities required for CDBB in the previous section are summarised Table 6. This illustrates the dominant capabilities supporting the future national challenges.

Table 6 - Summary of required capabilities for CDBB

CDBB Capability	Education					Healthcare						Transport							Energy					
	Aging population	Capability development	New educational products	Digitalisation	Distributed education	Aging population	Access to healthcare	Digitalisation	Precision medicine	Analytics	Healthcare business models	Reduction in air pollution	Decarbonisation	Changes in demand	Mobility-as-a-Service	CAV	Digitisation	Closer coupling	Changes in demand	Decarbonisation	Decentralisation	Digitisation	Customer experience	Electrification of transport
Demand and preference driven flexible infrastructure.	●	●	●		●	●	●				●													
Define service outcomes, capability and capacity, linked to the elements of the infrastructure and service required.		●	●		●		●				●				●	●							●	
Commercial structures for whole system (or components within whole system).	●	●	●		●	●	●				●	●	●	●			●		●	●				●
Socioeconomic evaluation of infrastructure/service impact and capability.	●	●	●		●	●	●				●	●	●	●			●		●	●				●
Incentivise whole system views of supply and demand.	●	●	●		●	●	●				●	●	●	●	●			●	●	●	●		●	●

CDBB Capability	Education					Healthcare						Transport							Energy					
	Aging population	Capability development	New educational products	Digitalisation	Distributed education	Aging population	Access to healthcare	Digitalisation	Precision medicine	Analytics	Healthcare business models	Reduction in air pollution	Decarbonisation	Changes in demand	Mobility-as-a-Service	CAV	Digitisation	Closer coupling	Changes in demand	Decarbonisation	Decentralisation	Digitisation	Customer experience	Electrification of transport
Abstraction of actors to value creation.			●		●		●				●				●								●	
Creation of relationships between provision, benefit, costs, risk and reward.												●	●							●				
Infrastructure use/value-derived and charging model based on demand, environmental conditions and affordability.															●	●					●			
Supply chain realignment based on value and creation of value chains.															●		●				●		●	
Creation of trusted value chain to warrant the commercially relevant transfer of information (or other outcome).															●						●			
Risk, liability and commercial impact for asset information availability, accuracy, integrity, relevance, completeness and timing.					●		●								●	●		●			●		●	
Awareness, training and development in an accessible and consumable form throughout the supply chain and society.				●	●			●									●					●		

CDBB Capability	Education					Healthcare						Transport							Energy					
	Aging population	Capability development	New educational products	Digitalisation	Distributed education	Aging population	Access to healthcare	Digitalisation	Precision medicine	Analytics	Healthcare business models	Reduction in air pollution	Decarbonisation	Changes in demand	Mobility-as-a-Service	CAV	Digitisation	Closer coupling	Changes in demand	Decarbonisation	Decentralisation	Digitisation	Customer experience	Electrification of transport
Methods to present trusted, secure, high benefit complex information and manage choice to digitally emerging or excluded members of society .				●	●		●	●			●			●	●		●					●		
Integrated platform.															●						●			
Creation of the data models and data sources that will underpin these systems.				●				●							●		●				●	●		
Integration of ‘slow’ and ‘fast’ data models.				●				●		●							●					●		
Standards, guidelines and codes of practice for data integration.				●				●		●							●					●		
Data privacy and security.				●	●			●	●	●	●			●			●	●			●	●	●	
Resilience of mission critical infrastructure.							●	●	●	●	●							●						

CDBB Capability	Education					Healthcare						Transport							Energy					
	Aging population	Capability development	New educational products	Digitalisation	Distributed education	Aging population	Access to healthcare	Digitalisation	Precision medicine	Analytics	Healthcare business models	Reduction in air pollution	Decarbonisation	Changes in demand	Mobility-as-a-Service	CAV	Digitisation	Closer coupling	Changes in demand	Decarbonisation	Decentralisation	Digitisation	Customer experience	Electrification of transport
Methods to trigger and reward behavioural change.												●	●	●					●	●	●		●	●
Inclusion of perceptive, subjective and objective criteria into system and business model.					●		●								●	●					●		●	

3. Current Capabilities

This section will review the current supply chain capabilities from a broad research perspective and the application within infrastructure, pertaining to healthcare, education, transport and energy sectors.

3.1. Literature review

Goods, services, and good and services

Michael Porter[54] wrote that while operational efficacy deals with achieving excellence in individual activities or functions, supply chain strategy defines the connection and combination of activities and functions throughout the value chain, in order to fulfil the business value proposal to customers in a marketplace.

The supply chain for the specification, design and delivery of built assets and across a portfolio of services throughout the asset lifecycle is a complex mixture of separate and combined provision of goods and services. This section will explore the current understanding of how the supply chains are structured in response to the provision and how digital approaches can be transformative.

Fisher[55] developed the model in Figure 2 to illustrate how a supply chain strategy is shaped by the interrelation among four main elements: the industry framework (the marketplace); the organisation's unique value proposal (its competitive positioning); its internal processes (supply chain processes); and its managerial focus (the linkage among supply chain processes and business strategy). Although each of these elements includes multiple factors, only some of those factors are relevant drivers for the formulation of a supply chain strategy.

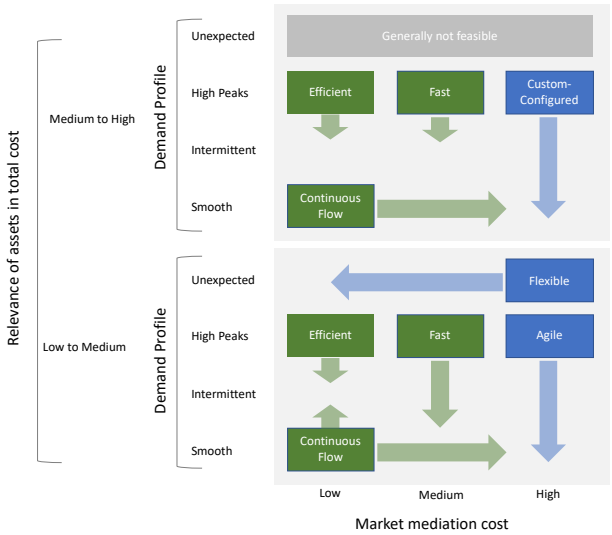

Figure 2 - Relationship of industry frameworks and generic supply chain models

The components of the industry framework are:

Demand variation, or demand profile, influences the stability and consistency of the manufacturing assets' workload, and consequently is a main driver of production efficiency and product cost.

[54] Michael E. Porter, Competitive Strategy: Techniques for Analyzing Industries and Competitors (New York: Free Press, 1980).
[55] Marshall Fisher, "What Is the Right Supply Chain for Your Product?" *Harvard Business Review,* March-April 1997, 105-116

Market mediation costs, defined as costs associated with the imbalance of demand and supply. Examples include product price markdowns to compensate for excess supply, and lost sales when demand exceeds supply. These costs, which reflect the unstable and fragile balance between lost sales and product obsolescence, arise from the consequences of the degree of demand predictability.

Product lifecycle, continually getting shorter in response to the speed of change in technology, fashion, and consumer product trends, affects the predictability of demand and market mediation costs. Consequently, it pushes companies to increase the speed of product development and to continuously renew their product portfolios.

Relevance of the cost of assets to total cost becomes critical in industrial sectors where business profits are highly correlated with the asset-utilisation rate. Companies fitting this profile must assure high utilisation rates, often to the detriment of working capital and service levels. In industries where the relevance of the cost of assets is low, companies may choose strategies that focus on responsiveness. In these cases, the asset-utilisation rate falls between high and low, but responsiveness to unexpected demand is high, increasing customer satisfaction and reducing market mediation cost.

With a focus on the provision of goods, there are six main supply chain models that almost all businesses adopt. These can be grouped into three main categories:

- Supply chain models oriented to efficiency.
- Supply chain models oriented to responsiveness.
- Supply chain models oriented to efficiency.

In industries where the value proposition is oriented to metrics such as high relevance of asset utilisation, low cost, and total cost, the end-to-end efficiency is given high priority. Examples of such industries include steel, cement, paper, low-cost fashion, and commodity manufacturing in general. Three supply chain models fall under this category:

The 'efficient' supply chain model This model is best suited to industries that exist in highly competitive markets with several producers, and customers who may not readily appreciate their different value propositions. These are usually commoditised businesses where production is scheduled based on expected sales for the length of the production cycle and competition is almost solely based on price. The steel and cement industries fall under this category. The key objective of the efficient supply chain model is that managers should focus on maximising end-to-end efficiency, including high rates of asset utilization, in a bid to lower costs.

The 'fast' supply chain model This supply chain model is best suited for companies that manufacture trendy products with short lifecycles. In order to keep up with fashion trends, consumers are mostly concerned with how fast the manufacturer updates their product portfolios. Companies that adopt the fast supply chain model focus on shortening the time from idea to market and maximising the levels of forecast accuracy, thus reducing market mediation cost.

The 'continuous-flow' model This model is ideal for industries with high demand stability. The manufacturing processes in a continuous-flow model are designed to generate a regular cadence of product and information flow. This supply chain model is suited for mature

industries with little variation in the customer demand profile. Competitive positioning for this model involves offering a continuous-replenishment system that ensures high service levels and low inventory levels at customers' facilities.

In industries that are characterised by high demand uncertainty and where market mediation costs is the top priority, supply chain models that are oriented to responsiveness are usually employed. These include:

The 'agile' supply chain model is ideal for companies that manufacture products under unique specifications by their customers. This model is mostly used in industries characterised by unpredictable demand. The model uses a make-to-order decoupling point that involves manufacturing an item after receiving customers' purchase orders. To ensure agility in the supply chain, managers focus on having the ability for excess capacity and designing manufacturing processes that are capable of the smallest possible batches.

The 'custom-configured' model is ideal where products with multiple and potentially unlimited product configurations are required. It features a high degree of correlation between asset cost and the total cost. Product configurations is usually accomplished during the assembly process where different product parts are assembled according to a customer's specifications. The custom-configured model combines the continuous-flow supply chain model and an agile supply chain. This is where the processes before configuration of the product are managed under the continuous-flow model, while downstream processes operate as an agile supply chain.

One of the most challenging supply chain models is where a high degree of flexibility is required in terms of required capacity, response time and variation.

The 'flexible' supply chain model This supply chain model is best suited for industries with high demand peaks followed by extended periods of low demand. This model is characterised by high adaptability with capability to reconfigure internal manufacturing processes so as to meet specific customer needs or solve customer problems. For this supply chain model to be successful, the management should focus on the following: ensuring ample flexibility with emphasis on rapid response capability, having extra capacity of critical resources, possessing adequate technical strengths, and developing a process flow that is quickly reconfigurable.

Dependent on the activity and stage in the lifecycle, the built environment has elements of most of these different models. This can range from the continuous flow model for the production of aggregates, to the custom configurable models, depending on the variation of schemes and the flexible model resulting from the cyclical nature of the construction phase in particular. During maintenance, the need for agility comes to the fore to respond to the needs of spares. Once in operation, the goods model tends to be used for consumable items that are related to the demand.

The authors would estimate that around 25-30% of the total cost in the construction phase is attributed to goods, with this reducing to around 15-20% during maintenance and operations. Over an asset operational period of just ten years, only around 15% of the costs incurred can be attributed to the well-studied goods supply chain in infrastructure, with the remaining being attributed to the less understood service.

The importance of service to our economy has been understood for many years by great scholars of strategy and economics. This includes:

The great economic law is this: services are exchanged for services...it is trivial, very commonplace; it is nonetheless, the beginning, the middle, and the end of economic science. Bastiat[56].

What is needed is not an interpretation of the utility created by marketing, but a marketing interpretation of the whole process of creating utility. Alderson[57].

The importance of physical products lies not so much in owning them as obtaining the services they render. Kotler[58].

Customers do not buy goods or services. They buy offerings which render services, which create value...activities render services, things render services. Gummesson[59].

The focus is not on products, but on the consumers' value - creating processes, where value emerges for consumers, and is perceived by them. Gronroos[60].

This acknowledgement of importance is not necessarily matched with understanding, particularly when related to the scope of CDBB.

This acknowledgement has gained attention primarily as the impact on GDP is understood[61]. A view is emerging that is refocusing supply chain management on partnerships, relationships, networks and value constellations[62]. Traditionally, services have been considered as residual from goods, rather than the end state and the dominant mechanism for trade.

The systems concept for supply chains has a long-established series of tiers where direct or indirect contact with the customer occurs[63]. In these tiers, business process and interactions are occurring: predominately a service transaction in the realisation of goods or fulfilment of an intangible operation.

The supply chain operational reference model[64] (SCOR) is seen by many as the de-facto method for standard strategy, performance management, and the process improvement diagnostic tool for supply chain management. It is predominately used for the supply of goods and the services associated with the supply of goods. Giannakis[65] explored whether the SCOR model could be used to develop a reference model both to describe and for use in service organisations. The research demonstrated that it is possible to use the model to conceptualise the capability and capacity of an organisation to provide a service offering. Yet, the research has not demonstrated that a manufacturing type approach could be applied to the service ecosystem.

Ellram[66] also analysed the conventional supply chain models, which included SCOR, and added the Hewlett Packard[67] model and the Global Supply Chain Forum (GSCF)[68] framework as additional

[56] https://oll.libertyfund.org/titles/bastiat-selected-essays-on-political-economy/simple
[57] https://helda.helsinki.fi/bitstream/handle/10227/412/WP_542_GronroosRavald.pdf?sequence
[58] Kotler: A Generic Concept of Marketing. Journal of Marketing 36, 46-54
[59] https://doi.org/10.1108/03090569610106635
[60] https://helda.helsinki.fi/bitstream/handle/10227/412/WP_542_GronroosRavald.pdf?sequence
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[63] Lambert, D.M. Martha, C.C. and Pagh, J.D. Supply Chain Management: implementation Issues and Research, International Journal of Logistics Management (28) 2007 pp 1-24
[64] Douglas M. Lambert. Supply Chain Management: Processes, Partnerships, Performance. 2008, p. 305.
[65] Giannakis, M. (2011). Management of service supply chains with a service-oriented reference model: the case of management consulting. Supply Chain Management: An International Journal, 16(5), 346-361.
[66] Ellram, L., Tate, W., & Billington, C. (2004). Understanding and Managing the Services Supply Chain. Journal of Supply Chain Management, 40(3),
[67] DOI: 10.1287/inte.25.5.42
[68] https://fisher.osu.edu/centers-partnerships/gscf

models or frameworks of note. The work concluded that while there are aspects of all of these models that can be used, the supply of services is different to the supply of goods and new models are required.

Lusch suggests the contemporary view of a service supply chain per se has evolved to a service ecosystem or network reflecting the different nature of the relationships involved. It is proposed that a service ecosystem is a real-time sensing and responding spatial and temporal structure of loosely coupled value, proposing social and economic actor, interacting through institutions and technology. This service ecosystem will coproduce service offerings, exchange service offering and co-create value.

Vargo and Lusch[69] researched the service economy and contemporary understanding of the provision of goods and services. This work challenged conventional wisdom to suggest that although goods are better understood, it is service that is the general case and less understood. This led to the development of Service Dominant Logic[70] (SDL), which contains the five axioms shown in Table 7. They also argue that there is a difference between a service and services. Services are intangible products, while a service is the use of resource or competence for the benefit of others, and transcends goods and services.

Table 7 - Axioms of service-dominant logic

Premise		Explanation
1	Service is the fundamental basis of exchange.	The application of operant resources (eg, knowledge and skills), 'service', is the basis for all exchange. Service is exchanged for service.
2	Value is always co-created by multiple actors, including the beneficiary.	Implies value creation is interactional and combinatorial.
3	All economic and social actors are resource integrators.	Implies the context of value creation is networks of networks (resource-integrators).
4	Value is always uniquely and phenomenological determined by the beneficiary.	Value is idiosyncratic, experiential, contextual, and meaning laden.
5	Value co-creation is coordinated through actor-generated institutions and institutional arrangements.	Institutions provide the glue for value co-creation through service-for service exchange

Their observation that value is a central theme is also of note. Classically value is defined in exchange and use. Value in exchange is the worth of something in exchange for something else denoted by the price and termed 'nominal value'. Whereas value in use is the usefulness of something, where benefit is afforded and satisfaction derived: termed 'true value'[71].

Building on the BS55 and ISO55001 standards, Parlikad[72] et al developed a structured methodology which applies a systematic approach to identifying the key stakeholders of the assets (for example, asset owners, maintenance contractor and the end users), their needs and

[69] Vargo, Stephen L. and Robert F. Lusch, (2004) "Evolving to a New Dominant Logic for Marketing," Journal of Marketing
[70] sdlogic.net
[71] https://www.adamsmith.org
[72] Parlikad, A, Srinivasan, R, Whole Life Value Based Decision Making in Asset Management. ISBN 978-0-7277-6061-6

requirements from the asset, and how these requirements are fulfilled by the effective maintenance policies adopted through the asset lifecycle. This ensures that the asset continues to provide the best value for money. The unique approach taken is the methodology Value Mapping Tool which assists in the visualisation of the connections and subsequent calculation of the impact of an asset or intervention.

Building on this work Wu et al[73] analysed the gap between traditional supply chain management (SCM) and what they call service science, management and engineering (SSME) which is analogous to the SDL developed by Vargo and Lusch. This research identified the following as key considerations in the service supply chain.

- An SSME-based supply chain encourages more effective and efficient ex-ante interaction and engagement, and fosters proactive dialogue and cooperation with customers. This is necessary as the exchange of experiences requires collaboration between various parties to design the configuration of the service-based supply chain.
- Blurring of intra-organisation and inter-organisation boundaries. It is crucially important that a supply chain can provide prompt, correct services to final customers. The SSME-based approach redefines the boundaries between and within organisations by linking divisions, and thereby shortens the supply chain.
- Virtual and physical integration. Designing a supply chain from the micro to the macro level requires that the chain should be integrated both virtually and physically.
- The role of ICT. Although the service industry has implemented IT and service-related processes for decades, redefining the scope of ICT to ensure that it is fully utilised is a critical issue. The importance of ICT in the supply chain has been well-documented; however, in a service-oriented supply chain, it is critical that ICT should be used to understand all elements of the value exchange.

While an institution or technology is a key to the ecosystem, the core is the information exchange that allows for the value to be realised. The manner in which this information exchange occurs uses information technology[74].

The use of information technology as the nervous system[75] of the service ecosystem was defined with seven enablers[7677]:

1. Good become embedded with intelligence.
2. As information technology improves, the ability to self-serve increases.
3. As information technology improves, the ability to serve others increases.
4. As the ability to communicate increases, the need to transport decreases.
5. As the ability to communicate increases, the ability to know and understand customers and suppliers increases.
6. As the ability to communicate increases, the ability to interact directly with customers and suppliers increases.

[73] http://dx.doi.org/10.1016/j.apmrv.2014.12.002
[74] Mokyr, J. Historical Origins of the Knowledge Economy, Princeton University Press, 2002
[75] Gunaskaran, A and Ngai, E. Information Systems in Supply Chain Integraiton and Management. Journal of Operational Research (159), 2004, pp 269-295
[76] Brown, J.S. and Duguid, P. The Social Life of Information. Harvard Business Review 2000
[77] Benkler, Y. The Wealth of Networks: How Social Production Transforms Markets and Freedom. Yale University Press 2006.

7. As the ability to communicate at lower cost increases, coordination between actors becomes more efficient and responsive.

Wang[78] et al argue there are actually three types of supply chain provision: service only supply chain (SOSC) which is a network of suppliers, service providers and consumers; goods only supply chain (GOSC) which provides tangible manufactured products, which rarely exist; and products service supply chain (PSSC) which is a hybrid that is the management of information, process, capacity, service performance, funds and forward and reverse flow of tangible goods in the creation of value.

The Infrastructure Client Group sponsored Project 13 is an industry led initiative to improve how infrastructure is delivered and managed. One of the key outcomes of the work is the Blueprint[79], which seeks to change the structure used for the infrastructure schemes. This is illustrated in Figure 3. The most significant changes to the structure are: that the owner is central and leads the enterprise, defining long-term value; suppliers and advisors have direct relationships with the owner; an Integrator actively engages and integrates all tiers of the market; and the key suppliers, owner, advisor and integrator work as one team to optimise value. This approach was developed to: reward the enterprise based on the value added to the outcomes and not the service provided; achieve a greater understanding of cost drivers and risk across all organisations in the enterprise, with commercial incentives for collaboration to jointly mitigate risk, and not seek to transfer; and establishing fundamentally different leadership, governance, behaviours and skills to succeed.

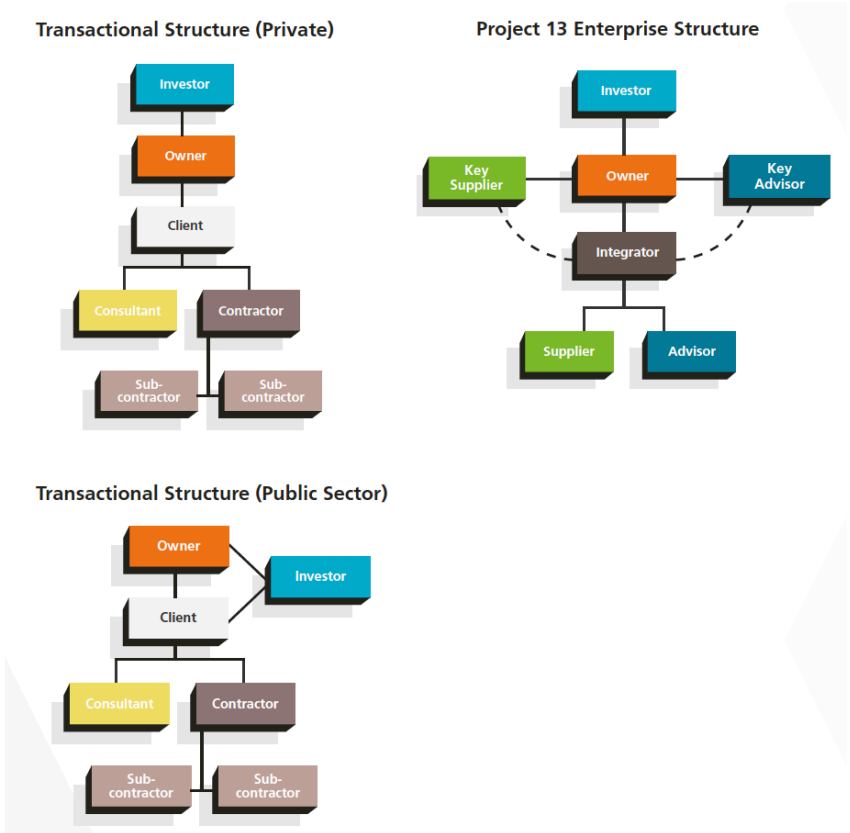

Figure 3 - Project 13 enterprise structure

[78] Wang, Y., Wallace, S., Shen, B., & Choi, T. (2015). Service supply chain management: A review of operational models. European Journal of Operational Research, 247(3), 685-698.
[79] http://www.p13.org.uk/wp-content/uploads/2018/06/P13-Blueprint-Web.pdf

Urtmetzer[80] et al developed a classification model for B2B organisations which illustrates how value is delivered and exchanged between the parties. This research showed that any organisation may have multiple different value exchanges and may be involved in multiple links between companies. When looking at the value exchange and the linkage between the companies in the value exchange, these connections may be defined or treated differently, depending on their individual condition. Even though the value delivered between the ecosystem firms is similar, the type of connection, its operation and its management may vary. This is illustrated in Figure 4.

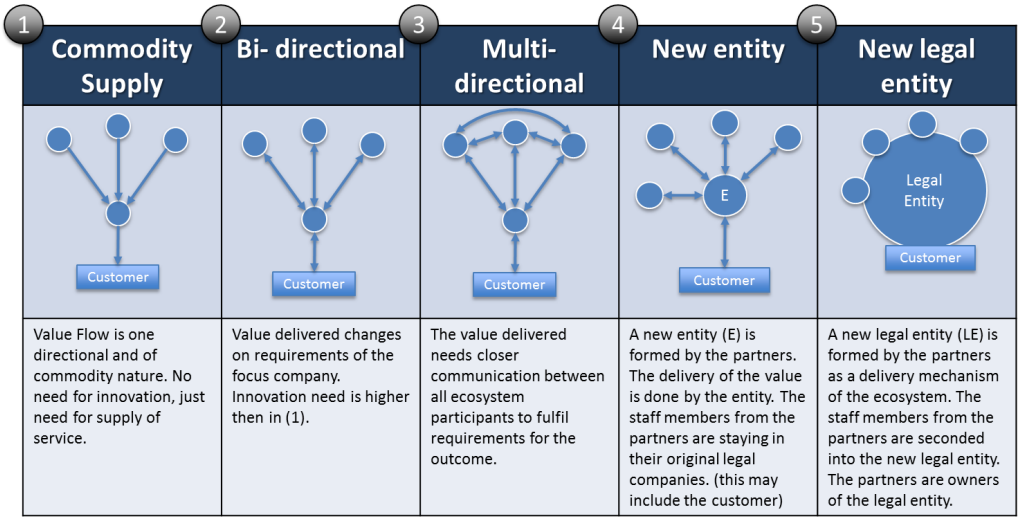

Figure 4 - Classification of B2B business value exchange

Achieving outcomes in supply chains

This next section will investigate the state-of-the-art in achieving outcomes in supply chains. Having established the purpose of a supply chain is to create value, it is essential to recognise that a hybrid services and goods supply chain model or approach will be dominant within the scope of CDBB, as well as appreciating how important information within the supply chain is and how outcome is defined, in order to achieve this value.

Traditional supply chain contracts are geared towards the provision of an output, rather than the outcome. Traditional contracting is the procurement by the client to private contractors who are selected by competition or pre-qualification and negotiation. Traditional procurement of goods and services has a long history as the favoured method for the delivery of public infrastructure. Public procurement by auction was evident in Mesopotamian city states as long ago as around 2,600BC, and at the times of classical Greece and the Roman Empire[81][82].

Traditional contracts are adversarial, and the degree of adversity is determined by the form of contract, the allocation of risk, mechanisms for dealing with disputes, the alignment of incentives and responsibility for decision-making. The arrangement for payment of the contractor is also important as it is this mechanism that determines which of the parties carries time and cost risk.

[80] Urmetzer, F, Neely, A, Martinez, V. The Journal of Japanese Operations Management and Strategy, Vol. 8, No. 1, pp. 18-34, 2018
[81] Cameron, R., & Neal, L. (2003). *The Concise Economic History of the World, From Palaeolithic Times to the Present* (4th ed.). London and New York: Oxford University Press
[82] Bernstein, W. J. (2008). *A Splendid Exchange, How Trade Shaped the World*. New York: Grove Press.

When carrying out work in a fixed price contract, much of the contractor's work is unobservable or either too difficult or costly for the client to monitor. In an adversarial contract, the incentives that drive the parties over the term of the contract are mismatched or non-aligned. Contractual disputes after the fact are common, absorbing significant management time, and are costly to resolve[83]. The client expects that the specified goods or services in accordance with the contract documents will be delivered on time and within budget. In a competitive bid market, the contractor will bid to win the contract and if successful, the manager's focus will be on optimising margins by taking advantage of an incomplete specification, change in scope of works or ambiguity in the contract - and disputes. Resolution of disputes does occur during the life of the contract although many claims may be unresolved long after the works have been completed.

Paying for services only when they are needed could be a future procurement model for many purchases that include a high level of service over time. The idea of paying for aircraft engines only when they are actually flying came about in the 1960s, when Bristol-Siddeley coined the term 'power by the hour'. When the firm was purchased by Rolls Royce in 1966, the concept (and the trademark) came with it. In the early 1990s in the wake of a world recession, many countries sought to improve microeconomic performance, reduce public deficits and unemployment, and renew aging infrastructure. These reforms led to wider use of outsourcing of government services, the privatisation of many state business enterprises, and the introduction of new privately-financed procurement methods. In fiscally constrained times, the appeal of private capital was also very attractive. The role of government also began to change from the ownership and production of public services to the purchase of services from private producers. In the years that followed, a number of new methods were adopted that took a very different approach to the relationship between the state as client and contractor as agent. The more common non-adversarial contracts are public private partnerships (PPPs) and outsourcing arrangements, including concessions and franchises. This group of procurement methods are based on a very different set of principles to traditional adversarial procurement and commonly feature the following characteristics:

- Long-term incomplete contracts.
- Bundled services.
- An output specification.
- A non-adversarial contract structure that encourages long-term relationship management to resolve disputes, the renegotiation of elements of the contract affected by change, and the maintenance of services.
- Significant risk transfer from client to the contractor.
- Contractor selection process that places equal or greater reliance on qualitative factors than on quantitative or price criteria.
- Greater alignment of incentives to encourage innovation and efficiency.

This long-term evolving works definition and output-based approach, where the parties work together, is known as 'alliancing'. As with traditional contracts, there are many forms of alliancing contracts, with the key elements being:

- Joint residual control and collaboration on sub-contractor selection.
- Sharing of information, innovation and technology.

[83] Love, P.E.D., Edwards, D.J., & Smith, J. (2006). "Contract Documentation and the Incidence of Rework." *Architectural Engineering and Design Management*, *1*: 247-259.

- An ‘open book’ project governance and accounting framework.
- Joint approach to costing (target cost estimate) and negotiation of the contractor’s margin.
- Aligned incentives driving the conduct of the parties.
- Joint selection of the project managers, sub-contractors, consultants and advisers.
- Risk of cost overrun borne by both parties and the contractor stands to lose all or part of its margin and corporate overhead.
- Cost savings and early completion gains shared between the client, the contractor and sub-contractors.
- Disputes resolved by alternative dispute resolution (ADR) methods with limited recourse to judicial proceedings.

When the desired outcomes are understood and can be contracted, this is known as Outcome-Based Contracts (OBC). Here the client rewards the contractor or service provider for achieving the outcomes of value within an overall package, as opposed to discreet elements. Normally there is a mechanism where underperformance is penalised based on the impact endured by the client (or a proportion of). Over performance, if of value, will attract an additional payment. Often an OBC will be executed by an alliance where there is a higher degree of uncertainty on the definition of the inputs, with surety of the expected outcomes:

- Outcomes and value of the outcomes are clear.
- All parties are involved in establishing the outcomes, the metrics and interdependencies and are jointly incentivised to achieve the outcome.
- All parties have the ability to execute their duties in the fulfilment of the outcomes.
- Externalities are understood and assigned to the party best able to manage.
- Risks are understood and assigned or shared with the parties best able to manage.
- Sharing of information, innovation and technology.
- Aligned incentives driving the conduct of the parties.
- Risk of cost overrun borne by both parties and the contractor stands to lose all or part of its margin and corporate overhead.
- Overperformance of value is rewarded, underperformance is penalised.
- Disputes resolved by alternative dispute resolution (ADR) methods with limited recourse to judicial proceedings.

While outcome-based contracting may be seen to provide answers to many of the alternative manners in which supply chains are engaged, they also have some challenges to overcome if the benefits of the approach is to be realised.

PPPs can be used to provide a route to deliver much needed investment, but can also attract a lot of criticism if they are not correctly structured or executed. A report by the Public Services Institute[84] has analysed a range of PPPs around the globe and concluded that they do not offer value for money, that they are too complex to arrange, the output or outcome is rarely assessed properly, and the private sector makes disproportional profits from the schemes. It reports that on average a PPP will cost government 25% more than if it was self-funded, while offering examples where the difference was 100-200% more than planned. They argue that the public sector can raise

[84] http://www.world-psi.org/sites/default/files/documents/research/rapport_eng_56pages_a4_lr_0.pdf

long-term, cheap finance at lower interest rates and over far longer time periods than any private company could. This could be achieved by using tax revenues or user charges as security to raise loans, or issue bonds to be repaid out of future income. It can decide on the balance between user charges and taxes to finance a service, and vary this balance over time according to changing circumstances. It can also choose to finance investment directly out of current revenues or taxes. The benefit of low borrowing costs can be gained by local as well as central and national governments. However, this is predicated on a government accepting a higher level of borrowing on the balance sheet which is often seen as politically unfavourable and a cause for concern due to potential over-gearing.

A study into the risks of outcome-based contracting from a providers' perspective by Hou and Neely[85], which combined literature review and case studies, concluded there are five principle risk factors involved that contribute to an outturn of commercial or operational risk. These can be grouped into contextual and stakeholder factors and are illustrated in Figure 5.

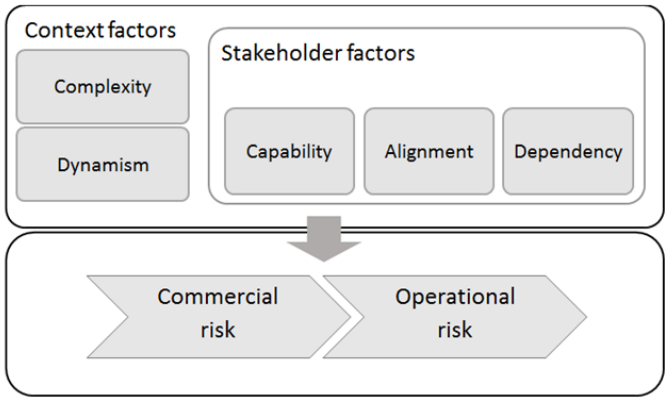

Figure 5 – Risk framework of outcome-based contracting from a provider's perspective

Complexity: the context where OBCs are adopted is very complex in general, where the providers are exposed to a lot of variables and uncertainty in many aspects. Five risk factors are categorised in this dimension: involvement of multiple stakeholders, diversified customer demands, unclear customer demands, complex contracts, and complex environment.

Dynamism: in parallel with the dimension of complexity which describes the current context of an OBC, another context factor is dynamism, which considers the timeline and reveals the fact that OBCs are usually long-term contracts, and dynamism and fluidity are unavoidable. The three risk factors in this dimension are dynamic customer demands, dynamic environment, and long-term contracts.

Capability: lack of capabilities from key stakeholders - the provider, the customer, and other partners - is an important reason why commercial risk and operational risk materialises. In this dimension, there are six risk factors that contribute to commercial risk and operational risk: providers' lack of capabilities to contract OBC, providers' lack of capabilities to deliver OBC, providers' internal inconsistency, providers' internal resistance, customers' lack of capabilities to consume the delivery and to play their roles, and other stakeholders' lack of capabilities to perform.

[85]https://cambridgeservicealliance.eng.cam.ac.uk/resources/Downloads/Monthly%20Papers/2017FebruaryPaperOutcomebasedservicecontracts.pdf

Alignment: mismatching between the provider and the customer is identified to be an important dimension of why commercial risk and operational risk happen. Alignment between the provider and the customer needs to be achieved in six aspects: goals, visions, practices, understandings, culture and bargaining power.

Dependency: this dimension emphasises first, the extent to which the provider depends on customers and other stakeholders for the delivery of the services and solutions; second, the extent to which the provider can control or influence the performances and behaviours of customers and other stakeholders; and third, the severity of consequences and impacts the provider has to bear due to the failure of customers and other stakeholders. Upfront investments, which is an important characteristic of OBCs, can also increase the provider's dependency, especially when the investments are contract specific.

This has particular challenge to governments and the oversight placed upon them[86]. They must be clear about the outcomes sought and how payments will be determined (for example, abatements and rewards). They must be aware of the line between maintaining appropriate contractual controls over the private sector operator, while at the same time not over-regulating to the point of stymying the benefits of that operator's efficiencies and ability to innovate. It is important they consider any unintended consequences of the outcomes sought and the contracting structure, especially cherry picking. Finally, they should specify how the outcomes will be measured. This may involve thinking about the counterfactual. For example, for the judiciary what would the recidivism rate be if the contractor did not deliver the services? If the government does not have this data on day one, then it may need a mechanism to transition to payment by outcome over the term of the contract, rather than paying for outcomes on day one.

Sandborn[87] et al investigated the opportunities and implications of outcome-based contracts for the designer. It is recognised that for a designer to produce an output that is supporting an outcome, a different approach to the design process is required. It will be necessary to adopt systems thinking, where the outcomes can be related to the contributory elements and the primary features or characteristics within.

The authors note this capability is not uniformly available within the design community where the business model has been to sell know-how by the hour and mitigate risk for the professional indemnity insurance. It should also be noted the quality of the information needed for designers to accept the risks and opportunity of outcome-based contracting is different. Currently, the client will expect the designer to accept all liability for the information used in the design, which prompts a process of resurveying and conservative approaches to solutions. Whereas, for an outcome-based contract the designer is incentivised to create the design best suited to achieving the outcome in the minimum time. This will force the client to either accept increased costs to recreate the necessary information or manage the information about the assets in accordance with a lifecycle approach such as ISO8001/150.

A study by Hughes[88] et al for Transport for London on outcome-based contracting concluded that clients must decide whether to seek innovation from the demand side or the supply side. If too

[86] https://www.herbertsmithfreehills.com/latest-thinking/infrastructure-trends-3-outcomes-based-approach-to-social-infrastructure
[87] Sandborn, Kashanipour, Goudarzi and Lei. Outcome-based contracts – concurrently designing products and contracts. 2016. The 5th International Conference on Through-life Engineering Services
[88] http://www.sci-network.eu/fileadmin/templates/sci-network/files/Resource_Centre/Reports/Performance-based_contracting_in_the_construction_sector.pdf

much reliance is placed on public sector clients who may lack the in-house expertise to create innovative demand, this may result in excessive expenditure on consultants, as well as an ineffective risk transfer. Performance-based contracts typically require suppliers to fund the development and installation work, foregoing payment until the operational stage (to varying extents, depending on strategic choices). Main contractors may lack the capital base on which to fund such contracts. If they rely on external funding, care is needed to ensure that contractual incentives and payment mechanisms do not follow traditional routes. The transition from product installation to service provision provides huge challenges in terms of organisational change for both supply side and demand side. They identified that clarity of funding is essential. Where a contract for services includes the commissioning of new buildings or infrastructure, the duration of the service element need not be as long as has been the case in the past. Short to medium-term contracts may be more effective than long-term contracts. In deciding on the duration of service contracts that require capital investment on the part of the supplier, clients should seek to keep the duration to a period that matches the amortisation of the suppliers' financing requirements.

Challenges and opportunities with current supply chains

Research by a variety of organisations, and the authors own experience, suggest the principal challenges seen during the construction phase with the current supply chains include:

- Client/Design Interface: difficulties in finding out client's wishes, changes of client's wishes, long procedures to discuss changes, interfaces with other relevant parties throughout feed and design period.
- Design/Engineering Interface: incorrect documents, design changes, extended time for design changes and approval, wrong calculations, designs not in accordance with the well-known construction methods, no constructability.
- Engineering/Procurement, Vendors Interface: inaccurate data, engineering drawings not fit for use.
- Engineering/Site Interface: engineering team not present on site for the field engineering.
- Engineering/Commissioning, Procurement/Commissioning, Main Contractor/Commissioning, Subcontractors, Suppliers/Commissioning Interfaces: difficult interfaces between various disciplines, problematic completion due to quality problems.
- Project Completion/Commissioning Interface: problematic completion due to quality or safety problems, problems with local communities.
- Procurement, Vendors/Suppliers Interface and Procurement, Vendors/Subcontractors: inaccurate data, technical specifications not met, other changes, lack of coordination, collaboration and commitment between suppliers, poor quality of materials and components.
- Procurement/Logistics Interface: not proper logistic studies, not effective logistics routes, not obtained permits and licenses needed, customs clearance delays.
- Logistics/Site Interface: large shipments, no proper packing, bad weather or political conditions, long storage period.
- Main Contractor/Subcontractors Interface: deliveries not according to planning, late deliveries of permanent materials, wrong and defective deliveries, large shipments, long

storage period, interfaces with several subcontractors and suppliers, poor training of contractor's suppliers, subcontractors and workers, inadequate management within the supply chain.

- Suppliers and Subcontractors/Site Interface: deliveries not in conformance with planning, wrong and defective deliveries, long storage period, subcontracted work not delivered according to main design, contract and planning, low productivity of several subcontractors, poor training of workers, deficient communication and information transfer.
- Site/Completion of Project and Project Completion/Commissioning Interfaces: problematic completion due to quality or safety problems, problems with local communities.
- Commissioning/Operation Interface: unresolved quality and technical problems, delayed operational time due to late completion.

The government's paper on the Supply Chain Analysis into the Construction Industry[89] is of interest. Although it has been half a decade since this report was written, the observations are considered valid today and for consideration by CDBB. It has shown that the majority of the work is delivered by Tier 3 or below, meaning there are two tiers of management activity above most of the executed work. There are typically 50-70 Tier 2 contractors on a job, with between 50-75% of the cost being dominated by a small number of Tier 2. A new team is formed for most jobs resulting in lost knowledge from previous schemes and the mobilisation inefficiencies occurring. The areas reported to provide the greatest impact on project performance were cited to be: certainty and prompt payment, repeat workload and early contractor engagement, incentive to contribute, good communication, well managed programme and good team relationships, and realistic pricing.

Service supply chains are not without their challenges. Ellarn[90] et al wrote that many professional service agreements are executed without clear specifications: there is a value leakage where checks and balances for acceptable levels of service are not provided. A study of Fortune 500 companies suggested this can result a transactional value of 5% being lost[91]. In addition, the service specifications are often difficult to develop: there is a considered bi-lateral misconception that either party in the service transaction know what good looks like and the process of alignment and articulation of expectations into a verifiable form is normally omitted. Often the development of Service Level Agreements focusses on the input rather than the outcome. What is clear is the role of information within any supply chain is key to providing visibility and transparency which will open up new possibilities for business models and relationships to be formed.

A study by Papadopoulos[92] et al suggested six focus areas that would address the current challenges.

1. Development of the supply chain: working with the supply chain to improve their performance which benefits their organisation and the programmes overall.
2. Performance measurement: well-designed performance measurement focussed on the outputs or outcomes that bring most value will enable an informed discussion with the supply chain.

[89] BIS Research paper 145, Supply Chain Analysis into the Construction Industry, October 2013
[90] DOI: 10.1287/inte.25.5.42
[91] Ammaral, J, Billington, C, Tsay, A. The Hidden Cost of Outsourcing. Edison Working Paper 2004
[92] DOI: 10.13189/ujm.2016.041002

3. Benchmarking: learning from others and sharing experience.
4. Knowledge management: supply chains for a programme or service provision are by their very nature transitory. They will exist in other forms to serve other clients. Capturing their knowledge will not only assist with market benchmarking, it can provide resilience in the event of their demise.
5. Optimisation: creating an environment of continuous improvement and elimination of waste from all perspectives is an influential lever to mutual improvement.
6. Technology: improving transparency, improving communication and streamlining the decision-making process.

Bankvall[93] et al argues focussing on activities and the need for coordination of sequential interdependence between them may prevent development of appropriate SCM models and efficient supply chain practices in construction. Unlike other industrial contexts, construction supply chains are not mainly subject to sequential but also to pooled and reciprocal interdependencies, and to interdependence owing to the need for synchronising a range of supply chains to each and every construction site. Directing more attention to resource utilisation throughout the supply chains may open up for new ideas of how to alter exchange and coordination patterns and create changes in the division of labour and relational patterns among the actors involved. Furthermore, taking into account the various actors' perspectives and their respective logic of economising may help to advance the understanding of how the performance of various parts of the complex construction network relate to each other and how different logics may be balanced.

Kaya[94] et al investigated the efficacy and efficiency of supply chains for building facilities management. The work focussed on the benefit of the common structure of master service provider compared with multiple service providers. The benefit of the master service provider is questioned. It recognises that someone, whether client or contractor side, needs to coordinate, drive efficiency and maintain records. However, when the expertise is buried in the supply chain and client is isolated from capability or innovation the outcomes achieved are diminished or the master service provider is seen to be providing a capability that is just a façade. It is suggested that greater certainty to invest in improvements along with visibility and transparency would yield improvements.

In comparison, the Royal Institution of Chartered Surveyors (RICS) and International Facility Management Association (IFMA) published a report[95] capturing best practice and identifying options which highlighted the importance of understanding the requirements and the relationships needed to successfully execute the contract. The report is very input and output focussed, and has not related the activities undertaken to the client's outcomes.

A number of facilities management organisations who recognise the challenge to the 'man-in-the-middle' approach have developed and deployed the approach of Integrated Facilities Management (IFM). This approach is to introduce an integrator who has domain expertise closely coupled with

[93] DOI: 10.1108/13598541011068314
[94] Kaya, S, Hinks, J and Alexander, K (2005) Innovation in facilities supply chain. In: Khosrowshahi, F (Ed.), 21st Annual ARCOM Conference, 7-9 September 2005, SOAS, University of London. Association of Researchers in Construction Management, Vol. 1, 411-9.
[95] https://www.rics.org/uk/upholding-professional-standards/sector-standards/real-estate/procurement-of-facility-management/

the client and their strategy, objectives and needs, who then manage the supply chain in the fulfilment of these goals. This is analogous to the earlier recommendations of Project 13.

Arora[96] has developed a method of modelling the supply chain topography to test the resilience of the supply chain to disturbances. These disturbances could include material shortages or organisations entering receivership as in the case of Carillion. The research would support understanding both static and dynamic structures of complex supply networks, and enable management to make informed decisions and prioritise particular operations.

Collaboration is a term often used when considering different departments or organisations working together. Within a supply chain this is of particular relevance and has proved to be particularly difficult to implement[97]. It is suggested that many of these difficulties are related to an absence of clarify of what collaboration actually means and implies, within a given context[98]. This is exacerbated when digital or e-business are promoted as the answer when the challenge to be addressed remains elusive[99]. Barrett[100] hypothesises segmentation of the supply chain to key customers and suppliers, and therefore gain a detailed understanding of the primary requirements that will be create the most value.

Information enabled supply chain

The research reviewed has all indicated the importance of information and sharing of information to create a high performing supply chain. This section will discuss how information is and can be used to enable the supply chain.

Core to the information enabled supply chain is BIM (Building Information Modelling). BIM is fundamentally the process that defines what and how information about the built environment is developed and shared. The purpose of BIM is to ensure that appropriate information is created in a suitable format at the right time so that better decisions can be made throughout the design, construction and operation of built assets.

At the current level of implementation, Level 2, building information models are likely to comprise a series of federated models prepared by different design teams, including model files, documents and structured data files containing non-geometric information about the facility, floors, spaces, systems and components. The creation of a geometric model and associated information as part of this process allows buildings to be conceived collaboratively and tested virtually, before they are built and operated for real. This should reduce problems encountered in construction and occupation.

The BIM information is stored in the common data environment (CDE). This is the single source of information for the project, used to collect, manage and disseminate documentation, the graphical model and non-graphical data for the whole project team. Creating this single source of

[96] https://doi.org/10.1007/s41109-018-0070-7
[97] Ireland, R. and Bruce, R. (2000), ``CPFR: only the beginning of collaboration'', Supply Chain Management Review, September/October, pp. 80-89.
[98] Barratt, M.A. and Oliveira, A. (2001), ``Exploring the experiences of collaborative planning: the enablers and inhibitors'', International Journal of Physical Distribution & Logistics Management, Vol. 31 No. 2,
[99] Sabath, R. and Fontanella, J. (2002), ``The unfulfilled promise of supply chain collaboration'', Supply Chain Management Review, July/August
[100] DOI 10.1108/13598540410517566

information facilitates collaboration between project team members and helps avoid duplication and mistakes.

The information required is defined as a series of Information Requirements derived from the Organisational information Requirements. These define the information needed to demonstrate the organisational outcomes, corporate decision-making, reporting and governance. The Asset Information Requirements define the information about the assets that will fulfil the organisational objectives, and the Employer's Information Requirements define the information that the employer wishes to procure in order to develop and operate a built asset. Setting this out in a contract document ensures that appropriate information is created in a suitable format at the right time. This is described as part of the BS1192[101] series and ISO19650[102].

The future supply chains are an instinct element of Industry 4.0, the fourth industrial revolution. They are not as often thought or marketed as just applicable to the manufacturing industry, and as the different sectoral models converge, evolve and develop they can be seen to be as just as applicable to construction, maintenance and operation. This is illustrated in Figure 6. This began with the first industrial revolution which brought a transformation in production and automation through steam and water power, then the second with electrification and more recently the third with the advent of the digital computer. Industry 4.0 – digitisation - is about companies orienting themselves to the customer through e-commerce, digital marketing, social media, and the customer experience. It is expected that virtually every aspect of business will be transformed through the integration of research and development, manufacturing, marketing and sales, and other internal operations, and new business models based on these advances. In effect, we are evolving toward the complete digital ecosystem where the supply chain will be a central element.

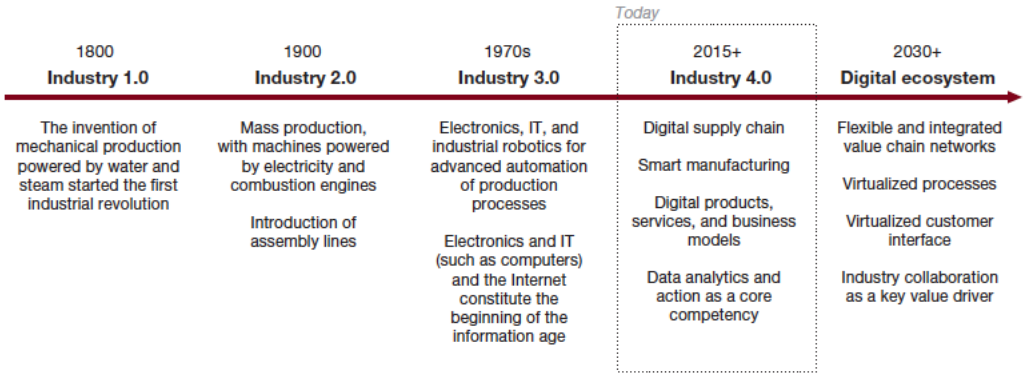

Figure 6 - Evolution of industrial revolution

PWC[103] wrote the digital supply chain sits at the heart of all this activity, and it is key to the operations of every company that manufactures or distributes anything. Indeed, for many companies the supply chain is the business. It extends the vertical integration of all corporate functions to the horizontal dimension, knitting together relevant players. These are the suppliers of raw materials and parts, the production process itself, warehousers and distributors of finished

[101] https://bim-level2.org/en/standards/
[102] https://www.iso.org/standard/68078.html
[103] https://www.strategyand.pwc.com/media/file/Industry4.0.pdf

products, and finally the customer through a network of sensors and social technologies, overseen via a central control hub, and managed through an overarching data analytics engine. This is illustrated in the diagram in Figure 7 and can be seen to be emerging today with new business models developing.

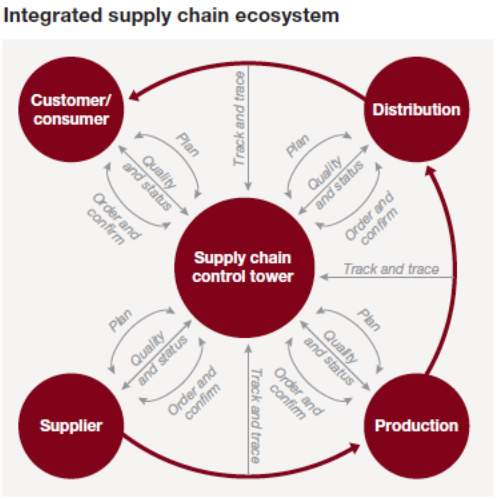

Figure 7 - Integrated supply chain

The business goal of the digital supply chain is to deliver the right product into the customer's hands as quickly as possible, but also to do so responsively and reliably, while increasing efficiency and reducing costs. This goal cannot be achieved unless the supply chain is fully integrated, seamlessly connecting suppliers, manufacturing, logistics, warehousing, and customers. The elements of an integrated planning and execution platform are shown in Figure 8.

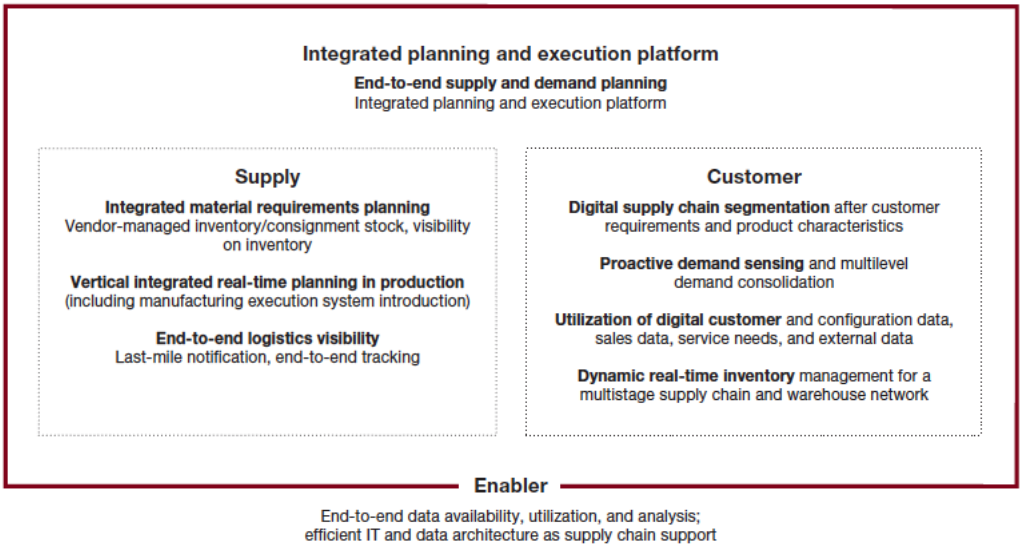

Figure 8 - Digital supply chain integrated planning and execution platform

Bain & Company[104] echoed the observations of PWC and developed consideration for the benefits and impacts that the increased visibility will bring. These include rising customer expectations as

[104] https://www.bain.com/insights/build-a-digital-supply-chain-that-is-fit-for-the-future/

there will be market parallels to be drawn, setting a precedence and micro-segmentation, enabling the tailoring of a service provision to be achieved.

Gartner[105] also recognised the importance of digital approaches to the supply chain. It is predicted here that a greater volume of data will be created through a greater understanding of the value of business information and fuelled by the explosion of IoT devices. This will provide greater insight through the advances with artificial intelligence and analytics, which will enable a greater degree of automation through robotic devices, process automation and decision support and assistance[106].

The Infrastructure Projects Authority[107] have stated the government will use its buying power to create new supply chains that support smart construction using off-site manufacturing. This demand is expected to be responded to with a development of capacity within the supply chain to use these techniques. They will also support the uptake of digital technology to improve the whole life costs of the assets. This is stated to be achieved through new commercial arrangements that will align vision, involve the supply chain earlier in the process and create a mechanism for a reward based on outcomes.

The digitisation of the supply chain enables companies to address the new requirements of the customers, the challenges on the supply side as well as the remaining expectations in efficiency improvement. When digitisation is applied to the supply chain the term Supply Chain 4.0 has been coined. Although this is focussed on the services to supply the goods, there are elements of interest to the scope of CDBB, in particular responding to the three key factors[108] that impact the ability to match supply to demand: demand uncertainty and the inability to accurately forecast demand, production uncertainties leading to changes in supply and lack of synchronisation among supply chain partners. An illustration of Supply Chain 4.0 by McKinsey[109] (similar imagery is produced by other similar organisations) is shown in Figure 9.

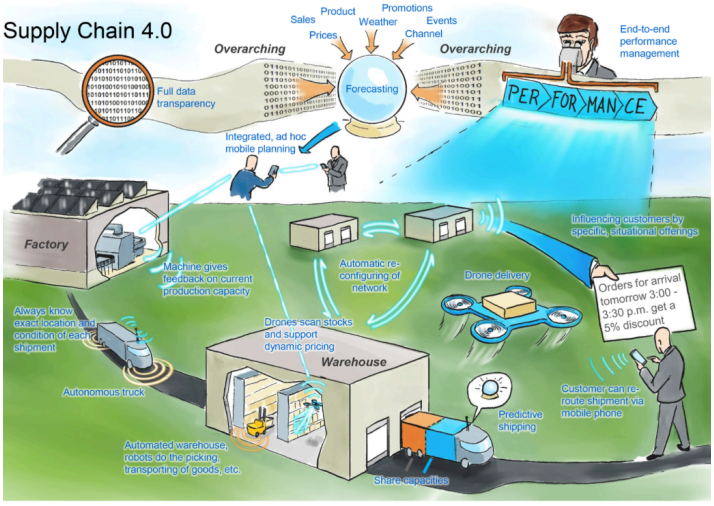

Figure 9 - Vision of Supply Chain 4.0

[105] https://www.gartner.com/smarterwithgartner/gartner-top-8-supply-chain-technology-trends-for-2018/
[106] https://www.gartner.com/smarterwithgartner/gartner-predictions-for-the-future-of-supply-chain-operations-in-2018/
[107] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/664920/transforming_infrastructure_performance_web.pdf
[108] https://www.industryweek.com/supply-chain/making-sense-supply-chain-40
[109] https://www.mckinsey.com/business-functions/operations/our-insights/supply-chain-40--the-next-generation-digital-supply-chain

This vision has three key components: data capturing and management, integrated process optimisation and increased automation. The data capturing and management component refers to the digitalisation of the entire process chain from master data management to scheduling to capacity statistics; integrated process optimisation describes the creation of a systems view of network and the actors within, informed by the data and continuously optimised rules developed using artificial intelligence; and automation ranges from decision support to autonomous vehicles for delivery. The central theme in this vision is to exactly match the supply to demand via the data within a systems model used for automation.

Universities and research establishments

Universities and research establishments working on the digitally enabled supply chain for infrastructure with a focus on outcomes are limited, as this is a new area of investigation. Those who are working in a similar or adjacent area are explored in this section.

The University of Reading's School of Construction Management and Economics has formed the Innovative Construction Research Centre[110] with three themes of interest: competitiveness, productivity and performance, through-life management and innovation, and innovative procurement. Professor Hughes in particular has advised a number of government departments and agencies on the supply chain within the built environment[111], along with the Henley Business School[112] who are researching supply chain and value chains across diverse sectors.

The University of Cambridge's Service Alliance[113] and the Centre for Smart Infrastructure and Construction[114] are of interest. The service alliance is focusing on the servitisation of the value chain with a focus on the production and support models rather than the built environment, but the principles should be applicable. Meanwhile, the Centre for Smart Infrastructure is researching how the value associated with infrastructure can be decomposed and the asset management optimised, amongst other things.

Work from the University of Warwick's Supply Chain and Operations Research Group[115] is currently centred around the manufacturing industry, but the areas of research should be applicable to show insight into the built environment. The specific areas of interest are: customer responsive supply chains – developing a new generation of business models that harness the potential of the internet, where consumers are customisers, retailers are virtual brokers and demand is fulfilled through a localised distributed manufacturing and logistics network; data driven decision making – to improve business decision making, turning the opportunity presented by 'big-data' into commercial success; and supply network structures – empirically assessing the performance of vertically integrated, networked and co-operative (hybrid) market structures to improve competitiveness.

The London School of Economics[116] has two interesting themes: information systems and organisational change in business firms and public sector agencies, as well as in multiple forms of

[110] https://www.reading.ac.uk/icrc/about/icrc-about-us.aspx
[111] https://www.reading.ac.uk/icrc/icrc-people/icrc-people-Professor-Will-Hughes.aspx
[112] https://www.henley.ac.uk/about-us/our-academic-areas
[113] https://cambridgeservicealliance.eng.cam.ac.uk
[114] https://www-smartinfrastructure.eng.cam.ac.uk
[115] https://warwick.ac.uk/fac/sci/wmg/research/supply_chain/
[116] http://www.lse.ac.uk/management/research/faculty-research-groups/isi?from_serp=1

collaboration across formal organisational boundaries; and the formation of digital infrastructures, their information content, the range of services they enable and the organisational processes they support. This is in addition to their broad supply chain expertise.

The Bartlett School at University College London[117] is investigating a broad range of areas of interest to the Centre: of particular relevance is the research into the management of project enterprises. This includes research on supply chain management within infrastructure and value creation.

The work by Imperial College London is an interesting subset of this research question. They have focussed on the management of the supply chain with particular focus on the new construction techniques such as off-site manufacturing[118]. This work has been undertaken alongside the Business School[119], who are researching the economic impact of infrastructure, in particular roads, energy and telecoms.

The Oxford University research into Law and Technology[120] offers an interesting perspective on how digital techniques can be used within the supply chain. This includes the used of digital ledger technology, and the concept of trusted and trustless transactions.

The University of West of England is researching smart contracts[121] in the delivery of projects and asset management. Their work on intelligent contracts is an extension to the research with BIM whereby the contractual performance itself becomes automated. This theme is continued at Portsmouth University[122] who has just started to research similar areas.

Project 13 was first set-out in the ICEs report[123] as a response to the analysis that the transactional model for delivering major infrastructure projects and programmes is broken because it prevents efficient delivery, prohibits innovation and therefore fails to provide the high-performing infrastructure networks that businesses and the public require. Project 13[124] have developed the enterprise model for infrastructure delivery discussed earlier in this report.

The European Construction Institute[125] is a pan-European network which reports to cover the entire asset lifecycle. It does have a broad membership, enabling insights into how other countries are addressing the challenges faced by the UK, including the digitalisation of the supply chain.

There are number of institutions researching broad supply chain management within the context of operational management. These may provide some general parallels of interest and would warrant further assessment. These include the Sheffield Management School[126], the Alliance Manchester Business School at the University of Manchester[127], the Aston Business School[128],

[117] https://www.ucl.ac.uk/bartlett/construction/research/themes/management-project-enterprises
[118] https://www.imperial.ac.uk/transport-systems/research/supply-chain-management/
[119] https://www.imperial.ac.uk/business-school/research/management/management-research/economics/
[120] https://www.law.ox.ac.uk/research-and-subject-groups/research-collection-law-and-technology/blog/2017/02/smart-contracts
[121] https://www1.uwe.ac.uk/et/research/caber/researchthemes/smartcontracts.aspx
[122] https://www.port.ac.uk/study/postgraduate/postgraduate-research/research-degrees/phd/explore-our-projects/exploiting-smart-contracts-and-blockchain-technology-blueprint-for-a-new-aec-industry
[123] http://www.p13.org.uk/wp-content/uploads/2018/04/From-Transactions-to-Enterprises.pdf
[124] http://www.p13.org.uk
[125] http://www.eci-online.org/what-is-eci/
[126] https://www.sheffield.ac.uk/management/research
[127] https://www.mbs.ac.uk/research/centres-and-institutes/
[128] https://www.advancedservicesgroup.co.uk

Cranfield University[129], Nottingham University[130], Strathclyde University[131] and the Cardiff University Business School[132].

3.2. Research Landscape

The literature review and research assessment highlight a number of key themes, as follows:

Concept of supply chain

- The classical models of the goods supply chain (product manufacturing and production) are well understood and documented. Six supply chain models have been identified and examples of use-cases assessed.
- There is considerable research available in the goods supply chains (product manufacturing and production) from a detailed to a global perspective.
- The infrastructure sector is noted to attribute around 25-30% of the total spend to goods during construction with around 15-20% during operation. The remainder is assigned to service related activities.
- The importance of service has been acknowledged for centuries, while research to understand it in the context of infrastructure and service provision is very limited.
- Goods biased supply chain assessment methods such as the Supply Chain Operational Reference (SCOR) model have been applied to service supply chains to assess performance. They have demonstrated that a single service entity could be represented but not the ecosystem. This is a key concept of supply chain and of particular importance for a service.
- The Service Dominant Logic model has been developed that sets out the key principles expected from a service supply chain and can be used as a basis of comparison or evaluation. It focuses on how value is created and exchanged between the parties. This has been successfully deployed.

Concept of value chain

- Value as a concept is cited by many without a considered or consistent view of what it actually means, particularly in the context of a service where the benefit can be monetised.
- A method for framing the value of an intervention to an asset has been identified for the purposes of asset management. The derivation of the value is an area for further development.
- Value realisation within a networked ecosystem is proposed as a means of reaching the value and avoiding layers of administration and overhead. In the author's opinion, the management of the residual risk current assumed to be managed by these tiers is not contemplated in sufficient detail.
- Different concept models for the value realisation have been suggested. The Infrastructure Client Group sponsored Project 13 builds on the concept of supply chain simplification and networks with an integrator to engage and integrate all tiers of the market, and where the key suppliers, owner, advisor and integrator work as one team to optimise value. This is

[129] https://www.cranfield.ac.uk/som/research-clubs/agile-supply-chain-research-club
[130] https://www.nottingham.ac.uk/business/about/research/divisions/OMIS/index.html
[131] https://www.strath.ac.uk/research/subjects/managementscience/operationssupplychainmanagement/
[132] https://www.cardiff.ac.uk/business-school/research/themes/logistics-and-operations-management

analogous to a full alliance model. The assignment of risk and reward is also an area for further detailed assessment.

Delivering outcomes

- Traditional supply chains are structured, incentivised and behave in a manner to optimise the output. The onus is on the client or the client's advisors to define exactly what output is needed, and provide sufficient constraints within the performance specification to the extent that the achieved output is aligned to the client's vision and values. If not, the scheme is either value engineered or subject to variations to optimise the contractor's position. It is the responsibility of the client to ensure that the outputs delivered by the supply chain will achieve the outcomes required.
- The architype outcome-based contract is the often-heralded Rolls Royce power-by-the-hour. Here the outcome is Specific, Measurable, Attainable, Realistic/Relevant and Time Bound (SMART) which means the relationship between the outcome and reward can be directly established.
- The commercial framework and behaviours necessary to realise this approach has been described. The greatest challenges arise with definition of outcomes and the value associated, ensuring all parties are aligned and have the ability to achieve the same outcome, and making sure externalities and risks are understood and assigned.
- When outcome contracts are delivered under PPP they have attracted considerable attention. There are many examples where PPPs have delivered the desired outcomes and offered good value. However, there is a tendency to report on the cases where either the supply chain made obscene levels of profit by leveraging the contract or the outcomes were not adequately specified, yielding undesirable results.

Challenges and opportunities

- The challenges the supply chain must address have been detailed. The root causes of the challenges are centred around the clarity of integrated and reconciled objectives, information that is fit-for-purpose and coordination of activities.
- The majority of the work on a typical scheme is delivered by tier 3 contractors who are under the control of a small number of specialist tier 2 contractors. This observation is persistent in construction and maintenance.
- Collaboration is another overused term, without understanding what it actually means and the context in which it is appropriate.

Information enabled supply chain

- Building Information Modelling and its application has had a significant impact on the sector providing better definition of data, transparency of deliverables, understanding of the non-physical attributes and consistency of handover throughout the lifecycle.
- The information requirements for an organisation extend from the asset information per se, to all information needed to provide the service and fulfil an enterprise's purpose or mission.
- Supply Chain 4.0, emerging from Industry 4.0, is purported to be a response to many of the supply chain challenges. The research has shown how it assists with the material supply chain management through greater visibility of information about supply and demand, and the optimisation of activities balancing these objectives.

- Away from the branding and hype of x4.0, the principle of having greater transparency of activities and using information to make better decisions is robust and aligned with leading industry thinking.

The research identified is illustrated in Figure 10. This illustrates the research landscape for the aforementioned categories and shows that while there is considerable activity in this area, there are some white spots emerging that will require further research. A mapping of the research gaps against the CDBB required capability and industry drivers is shown in Table 8. This illustrates the key areas to consider for further research are the majority of the areas identified as needs in the analysis:

- Demand and preference driven flexible infrastructure.
- Define service outcomes, capability and capacity, linked to the elements of the infrastructure and service required.
- Commercial structures for whole system (or components within whole system).
- Socioeconomic evaluation of infrastructure/service impact and capability.
- Incentivise whole system views of supply and demand.
- Abstraction of actors to value creation.
- Creation of relationships between provision, benefit, costs, risk and reward.
- Infrastructure use/value-derived and charging model based on demand, environmental conditions and affordability.
- Supply chain realignment based on value and creation of value chains.
- Creation of trusted value chain to warrant the commercially relevant transfer of information (or other outcome).
- Risk, liability and commercial impact for asset information availability, accuracy, integrity, relevance, completeness and timing.
- Awareness, training and development in an accessible and consumable form throughout the supply chain and society.
- Methods to present trusted, secure, high benefit complex information and manage choice to digitally emerging or excluded members of society.
- Creation of the data models and data sources that will underpin these systems
- Integration of ‘slow’ and ‘fast’ data models.
- Standards, guidelines and codes of practice for data integration.
- Methods to trigger and reward behavioural change.
- Inclusion of perceptive, subjective and objective criteria into system and business model.

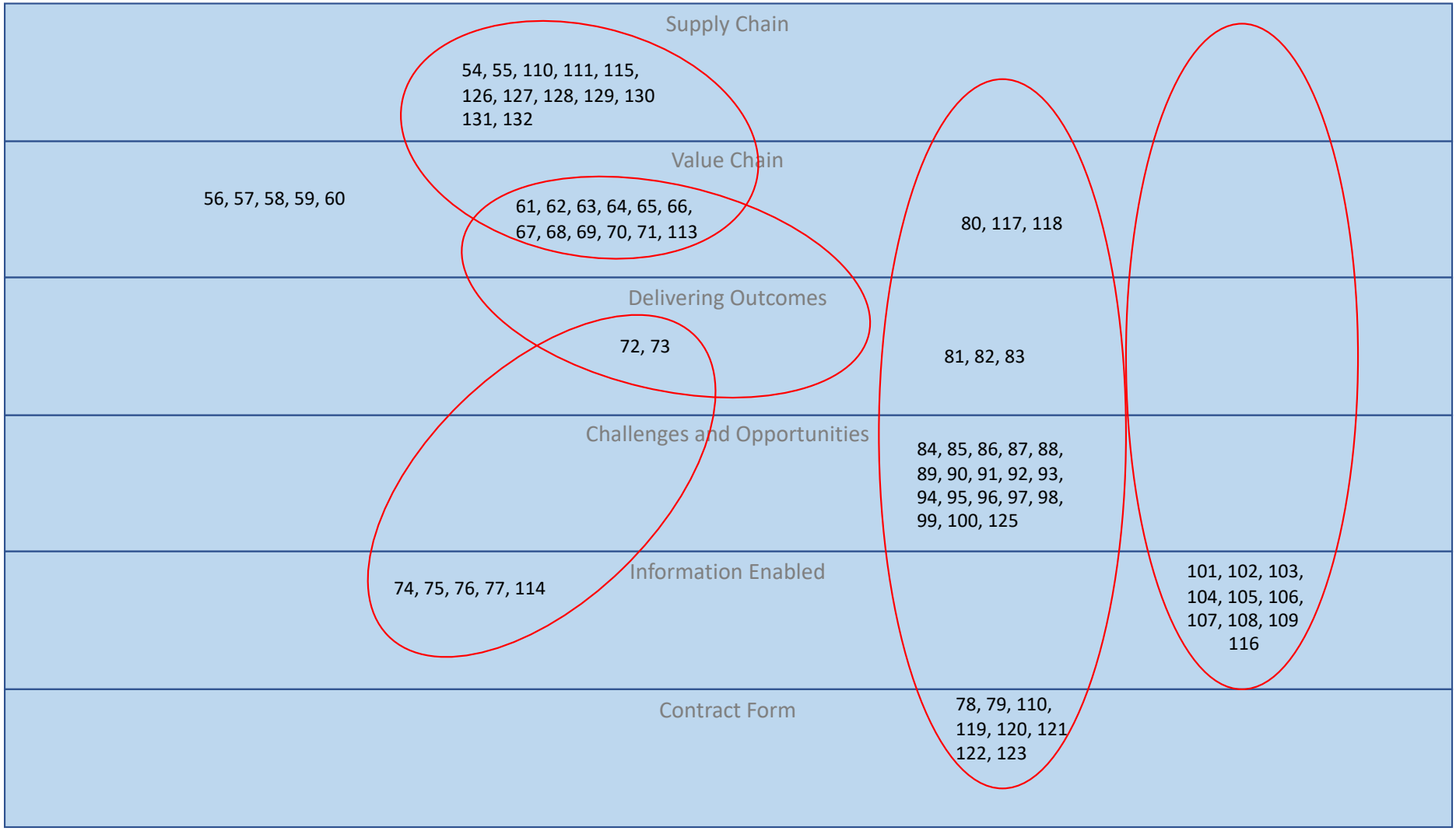

Figure 10 - Supply chain research landscape

Table 8 - Comparison of research gaps to CDBB required capability and industry drivers

CDBB Capability	Research Gaps	Education					Healthcare						Transport							Energy					
		Aging population	Capability development	New educational products	Digitalisation	Distributed education	Aging population	Access to healthcare	Digitalisation	Precision medicine	Analytics	Healthcare business	Reduction in air pollution	Decarbonisation	Changes in demand	Mobility-as-a-Service	CAV	Digitisation	Closer coupling	Changes in demand	Decarbonisation	Decentralisation	Digitisation	Customer experience	Electrification of transport
Demand and preference driven flexible infrastructure.	■	●	●	●		●	●	●				●													
Define service outcomes, capability and capacity, linked to the elements of the infrastructure and service required.	■		●	●		●		●				●				●	●							●	
Commercial structures for whole system (or components within whole system)	■	●	●	●		●	●	●				●	●	●	●			●		●	●				●
Socioeconomic evaluation of infrastructure/service impact and capability.	■	●	●	●		●	●	●				●	●	●	●			●		●	●				●
Incentivise whole system views of supply and demand.	■	●	●	●		●	●	●				●	●	●	●	●			●	●	●	●		●	●
Abstraction of actors to value creation.	■			●		●		●				●				●								●	
Creation of relationships between provision, benefit, costs, risk and reward.	■												●	●							●				
Infrastructure use/value-derived and charging model based on demand, environmental conditions and affordability.	■															●	●					●			
Supply chain realignment based on value and creation of value chains.	■															●		●				●		●	
Creation of trusted value chain to warrant the commercially relevant transfer of information (or other outcome).	■															●						●			

CDBB Capability	Research Gaps	Education					Healthcare						Transport							Energy					
		Aging population	Capability development	New educational products	Digitalisation	Distributed education	Aging population	Access to healthcare	Digitalisation	Precision medicine	Analytics	Healthcare business	Reduction in air pollution	Decarbonisation	Changes in demand	Mobility-as-a-Service	CAV	Digitisation	Closer coupling	Changes in demand	Decarbonisation	Decentralisation	Digitisation	Customer experience	Electrification of transport
Risk, liability and commercial impact for asset information availability, accuracy, integrity, relevance, completeness and timing.	■					●		●								●	●		●			●		●	
Awareness, training and development in an accessible and consumable form throughout the supply chain and society.	■				●	●			●										●				●		
Methods to present trusted, secure, high benefit complex information and manage choice to digitally emerging or excluded members of society.	■				●	●		●	●			●			●	●			●				●		
Integrated platform.																●						●			
Creation of the data models and data sources that will underpin these systems.	■				●				●							●		●				●	●		
Integration of ‘slow’ and ‘fast’ data models.	■				●				●		●							●					●		
Standards, guidelines and codes of practice for data integration.	■				●				●		●							●					●		
Data privacy and security.					●	●			●	●	●	●			●			●	●			●	●	●	
Resilience of mission critical infrastructure.								●	●	●	●	●							●						
Methods to trigger and reward behavioural change.	■												●	●	●					●	●	●		●	●
Inclusion of perceptive, subjective and objective criteria into system and business model.	■					●		●								●	●					●		●	

3.3. Domain review

The assets within the built environment underpin a contribution of over £600bn each year to the UK economy, with millions of people and thousands of companies involved in this value creation. The sector is complex, diverse, fragmented and under tremendous pressure to improve productivity and remain financially viable and stable.

A series of stakeholder interviews were conducted across the education, healthcare, surface transport and energy sectors, and at different levels within the respective supply chains. The interviews were conducted under the Chatham House Rule[133] for expediency and to get an honest opinion, avoiding approvals required from government or other organisations. The participants included in the market engagement included:

- Regulators.
- Government: National.
- Government: Local.
- Infrastructure creators.
- Infrastructure maintainers.
- System Operators.
- Service Providers.

The interviews were semi-structured and guided, but not constrained. These interviews were conducted to understand the purpose, vision, mission and strategies of the different organisations, and to gain an insight to the following questions:

- How is the supply chain performing?
- What are the challenges to be addressed and why?
- How is value determined?
- How are outcomes considered?
- What is the appetite for risk and reward?
- How can information transform the supply chain?
- How capable is the industry to use information?

The stakeholder engagement has sought to gain insight from a cross section of the supply chain concerned with education, healthcare, energy and surface transport. However, it is a finite sample of the market and a finite sample of individuals in the organisations. Therefore, it is likely there will be exceptions and other views and capabilities expressed. We have endeavoured to select the target organisations as representative of the market and interviewees within the organisations who have positions that would require knowledge in this regard. We also cross-checked market knowledge during the interview to validate insight and opinions.

The interviews provided a rich insight into how services are defined and how the underlying infrastructure is considered. This section draws out the key themes from the stakeholder interviews across the sectors and throughout the supply chain.

[133] https://www.chathamhouse.org/chatham-house-rule

3.3.1. What problem needs solving?

Throughout its lifecycle, the supply chain within the built environment is diverse and competitive. Across this supply chain there are many parties who have established a niche within a specific sector, location or stage in the lifecycle or are individuals with access to or knowledge of a particular technology or technique.

The consultations at various points within the supply chain and lifecycle illustrated there is a good awareness of digital throughout the supply chain and across the lifecycle. Each person had their own examples of how 'digital' has helped their business within their own discreet position. These ranged from having drawings available on a tablet which saved them carry out-of-date information around in paper form, to guided diagnostic software for a building management system, to route optimisation algorithms for a transport operator. All examples generally helped with the efficiency of their current process.

The 'digital' examples provided were frequently stand-alone solutions that were unconnected to their other business systems, let alone those of collaboration partners or other members of the supply chain. One distinct and reassuring exception was the use of building information modelling data, albeit it was often seen as a separate activity alongside their other activities.

The interviews generally took one of two distinct paths: either the interviewee was suitably digitally savvy to understand the art-of-the-possible and had a strategy for implementation within and external to their organisation (to a greater or lesser extent) or there was a lack of surety and unease about what and how to introduce and the tangible benefit of an intervention.

The question of 'what does this help me do better?' was a recurring statement, and a desire to understand how to leverage for competitive advantage was a consistent undertone.

3.3.2. Defining outcomes and value

The concept of outcome-based contracting was discussed in detail. It is known by most and parties close to large or government clients particularly understood the principles that enable a successful implementation. The few who were involved directly or closely with an outcome-based contract acknowledged the challenge in defining an outcome (where it was a collaborative process); in understanding how a prescribed outcome will be achieved by their actions; or how externalities will not present an unrealistic up- or downside. The outcome was generally reported to be a number of indicators (KPIs) with a reward weighting associated.

The consultation explored what is an outcome, an end user or socioeconomic outcome or an intermediate outcome that provides a benefit to another party to realise the ultimate outcome and release benefit. It was concluded that both are relevant and the thoughts, concerns and opportunities are equally applicable.

The commercial mandate of the organisations was understandably front and centre of all discussions: how am I going to make my money, what is my risk exposure and how can I gain surety? Where this was unclear or subject to externalities, the expectation for an upside grew and the team mobilised to mitigate risk and ensure the likelihood of a demonstrated outcome increased.

When there are a number of parties directly involved in achieving an outcome and there is mutual dependency, there is normally a Joint Venture (JV), Special Purpose Vehicle (SPV) or alliance formed in either an incorporated or non-incorporated form. For this to be a functional relationship, there must be shared values and aligned objectives with consummate risk and reward. Otherwise, and the consultation supports this assertion, the JV, SPV or alliance becomes dysfunctional, frequently dissolving or crawling along to completion, with neither party investing in the relationship and seeking to extract as much value from the arrangement as possible.

When subcontractors are instructed, it is challenging to be truly back-to-back unless there is a direct link between their activities and the outcome. If the link was key to achieving the outcome, it was suggested by some that they should be a member of the JV, SPV or alliance to share the risk and increase leverage. For those subcontractors where the link to the outcome cannot be established and commercialised, a traditional output approach is needed. This in itself presents an emerging risk for the JV, SPV or alliance, as there is a bridge to be established between the outcome and the output - exactly as would normally be held by the client. This, therefore, needs to be described in terms that link the output to the outcome, reported to be a challenge for many within the supply chain to achieve from a principle and negotiated perspective. This was reported to leave a disproportionate level of risk with the JV, SPV or alliance, which invariably still resides with the client as the ultimate beneficiary.

Notwithstanding the difficulty in defining the outcome or outcomes, assigning a value to that outcome or outcomes was the next level of challenge. As for the contractual arrangements to drive the right behaviours, there must be an alignment between reward and remuneration, otherwise human (and certainly business nature) is to focus on the components with the highest reward. The feedback from the consultation, from those defining the values and those executing works and services where the value is a component in the reward mechanism illustrated, was that despite the attempt at a scientific approach, there is a tendency to be subjective at best and at worst, arbitrary.

3.3.3.Simplicity

A common theme in the feedback is where the contractual payment reward mechanism is overly complex. This was cited as making the perceived benefit and the potential of gain of transparency burdensome for the client, while unattractive during acquisition and tainted during execution for the contractor.

For the client, the need to have a fair and proportionate reward that can demonstrate value for money is essential. If there is ambiguity that can be leveraged, this may result in poor value for money for the client (and tax payer) from both an output and outcome perspective.

For the contractor the evaluation of the opportunity can be difficult to model and therefore assess the outturn. This leads to uncertainty, which leads to risk assignment, which leads to inflated costs. In addition, during execution, the mechanism or number of terms or subjectivity around evaluation of performance can have elements of subjectivity, which frequently leads to dispute.

Discussion with the interviewees left the impression that this is an area that would enable an elegant articulation of the reward mechanism through a better understanding of the other aspects discussed in this section. This, in turn, would motivate the contractor and provide the client with the desired outcomes delivered as value for money.

3.3.4. Close and loose coupling

Linked to the definition of the outcomes and simplicity is the theme of coupling, and whether there is a causal relationship between the asset and the outcome. This demonstrated a number of points for consideration:

Close coupling

The rail network provides a good illustration of where this coupling is close and causal. Here, the maintenance contractor for a section of permanent way has a direct relationship on Network Rail's ability to provide the train operating company access for the delivery of a service, which may attract a rebate for the passenger. Therefore, if the maintenance contractor is late completing the works it follows the reward mechanism reflects consideration for any delay caused.

The degree and boundaries of this direct coupling was tested with interviewees. It was suggested that if transport were a means to an end for an individual to complete their duties that bring economic value, would there be an appetite to link a maintenance contract to economic value? The response was a unanimous 'no' as there are too many variables and the coupling becomes weak at this point.

That said, discussion with the providers of this type of service has illustrated there is an appetite for a greater risk exposure if there is an ability to manage the risk, if the reward is incentivising, if the penalty is balanced, and if a relationship can be demonstrated without excessive externalities.

Loose coupling

The education and healthcare sector provide some good examples of loose coupling. The literature survey illustrated where research had shown that an improvement of the school building would increase academic attainment, or a modern hospital would have a lower level of MRSA. Speaking with the supply chain for both the provision of the infrastructure and the operation of the service, shows that currently, and with the existing contractual relationships and roles, there was neither the appetite nor the desire for a constructor or maintainer to be rewarded for the health or educational outcomes. This is because there are so many other factors and externalities to be considered. This does not negate the discussion and definition of the enablers of outcomes, and to describe these as outputs or outcomes for a particular stage in the lifecycle. This did attract positive feedback but a cautious note round the existing capability to establish, value and respond to these requirements.

No coupling

The consultation provided an insight that was difficult for many to articulate: interpreted as a reticence borne from a knowledge gap or political concern to challenge the new digital future where everything is connected to everything is the answer in all cases. There is a concern that often the causality and therefore the coupling is so weak or has so many transactions or is

subject to indeterminant externality, that it simply does not exist in any meaningful form. Yet this is flying against much of the industry hype and accepted norms established and being proffered in the board rooms and expert groups.

Single and multiple system coupling

The examples given are all for single and quite tightly bound systems. We have learned that most systems are in fact systems of systems, which may introduce horizontal as well as vertical dependencies. For example, the relationship between the developer of an out-of-town shopping park and the rent they can attract based on the revenue expectations of the tenants will probably have a tighter coupling with the transport network and access/egress to the site than the building itself.

Significance

The stakeholders all discussed significance, primacy and operating between limits of acceptability. Digging into this further, this meant that the concept of causality and coupling is gaining understanding, but subjectively and intuitively many feel there are some factors of greater significance, and others that as long as they fall within acceptable limits are irrelevant. It was also noted that significance changes within sectors and over time as expectations evolve.

3.3.5. Balance of risk and reward

The consultations showed there is an appetite for greater risk if the ability to earn a greater reward is available. There was a concern expressed where clients attempt to off-load significant risks to the supply chain. These are then difficult to manage, but the contractors have no perceived option but to accept these risks, often by playing them down with their own risk managers and then working through them during the execution phase. This is clearly a dangerous approach as if they materialise the impact on all parties is often greater than the measures to mitigate.

A scenario where a proportion of the fee would be contingent on the outcome being achieved was tested with those within the earlier stages of the lifecycle, who had a direct and causal relationship with the outcome of the service provided. This received a mixed response, which centred around:

- The size of the reward.
- Whether the reward would be greater than the fee that could be earned in a traditional contractual relationship.
- Whether the cost of capital for any deferral would be recovered as part of the higher fee.
- That not all of the fee would be deferred or contingent. There is a sense that costs and a portion of overheads are required to maintain liquidity, with a conversation to had around profit.
- The degree of certainty.
- Their ability to influence how outcome was achieved and the possibility of intervention or remedy if the service provider did not execute their obligation.
- How the outcomes would be measured and the information.

- That the deferred fee cannot be deferred too far in the future. The question of how far was again met with a message of risk and reward within reason.

The reverse scenario, where a proportion would pay a fee to the infrastructure providers contingent on the outcome being achieved, was tested with those within the service providers who had a direct and causal relationship with the infrastructure to provide an outcome. This received a more positive response, with some words of caution:

- It mitigates the investment risk.
- It helps their cashflow.
- The deferral needs to be a significant portion which includes cost and overhead, otherwise it is just the profit that is at risk which is not significant enough.
- It providers leverage over underperforming assets.
- It binds the stages of the asset lifecycle closer, to focus on the outcome.

Clearly there is a gap in places, but the principle of a closer coupling of the enablers and providers is of interest.

This approach is worthy of note where constructors taking other roles in the asset lifecycle are emerging. Recently Vinci who already operate a large number of the French Autoroutes now has the controlling share in Gatwick Airport, while Ferrovial, with a history of road build and operate, already have a stake in Heathrow.

3.3.6. Transactional efficiency

Even though there was a focus on delivering outcomes throughout the lifecycle, the theme of the potential around transactional efficiency attracted discussion, as a means by which digital intervention can assist the supply chain in achieving an outcome. The interviewees cited the inefficiencies currently occurring throughout every stage of the lifecycle, ranging from the trouble finding data, trust in the source data which requires verifying or re-procuring, absence of proper requirements which lead to ambiguity of intent and challenge during verification and man marking throughout the process, multiple handling of information, and incomplete information being provided at touchpoints or handover. Using digital approaches to create information integrity throughout the lifecycle would reduce the overhead and inefficiencies currently seen. The use of blockchain for commercial transactions and collaboration platforms was an example cited. What was not cited and, when discussed, not appreciated, is the underlying common data models and ontology needed for the system to system interoperation.

3.3.7. Data governance

All those engaged during the consultation understood the importance of data and the material impact on all parties by the information created as the currency for the transactions. There is a recognition that the quality of information within many businesses is lower than would be aspired, and there is some nervousness if this substandard information is the basis for a financial transaction. There was great discussion about how to address this from a fundamental perspective and how to develop the integrity of the information provenance.

What resonated with all was the need to keep things simple, even if this is imperfect as confidence builds.

There is a considered gap in the understanding of data governance and the principles of ISO 80001 and how this can be applied within an organisation as part of its core business processes to underpin a data driven business. Those consulted who had an appreciation of data governance often held a belief this something that 'IT do' rather than it receiving the prominence that is necessary. This is explored further in the section regarding training.

Everyone recognises the role that blockchain may play as the marker for transactional integrity (even though the differentiation between cryptocurrency and distributed ledger technology is not well understood), but how this can be realised and what it means for businesses is an area that may be worthy of further investigation.

All parties in the supply chain have insurances to mitigate against contemporary risks. The need for organisations to consider the warranties needed for information risks and how to mitigate them came as a surprise to many during the discussions. Having a twelve-year latent defect period is a calculable and familiar risk, however offering a warranty on the information provided to an operator is an area that has not even been contemplated by many.

3.3.8. Legacy systems

Building on the theme of data governance, when pressed many organisations reflected on the robustness of their existing systems to provide information that is fit-for-purpose. Many of the information systems involve several steps of 'hand balling' the data: having multiple instances of the same information where the provenance or purpose not understood, and its usage controlled. Furthermore, there was uniform acceptance that the structure and definition of the different data types across the businesses means combining and integrating is always a challenge. The prevalence of the use of Excel as a key business system and for some, a mission critical system, is of concern.

There is a general acceptance that something will need to change and, in many cases, that the systems created to help are hindering progress. There was concern of the size of the task, that 'all IT jobs overrun and overspend' and knowing where to start. The pace of change is causing inaction by many, as there is an expectation the next big thing is just around the corner and if they move too quickly, they will only need another iteration. A number of people noted the need to have masterclasses or playbooks of similar organisations to reference and learn from across the sector, as it is a common problem.

3.3.9. Training and capability

Despite the progress made with information awareness and how it can bring value, along with the specific skills to create and manipulate building information models, the underlying digital capability was cited as poor. There is a desire to adopt and transform, with a lack of confidence and capability to know how. There is high (and unfair) expectation of the young and early career individuals to sort through 'this digital stuff, they are digital natives after all'. The hype around the subject is unnerving some and confusing many.

Some cited the teaming-up of the digital natives with mid/late career individuals to provide bilateral upskilling. These examples were heart-warming as it gave experienced people a platform to share their wisdom to individuals who needs to gain competence rapidly if their latent talent is to be used to best effect. In addition, the latent talent could be used to help people gain confidence with new environments and methods.

The strategic information capability in many organisations has been seen and was offered as an area for capability building. There was a general concern about IT consultants flying in and recommending large IT change programmes that few within the organisation actually understood.

The key messages have been interpreted and overlaid to the CDBB required capability matrix in Table 9. This shows a picture building where there are national requirements, and where there are gaps in research and domain capability. This is explored further in the next section.

Table 9 - Domain capability gaps

CDBB Capability	Domain Gaps	Research Gaps	Education					Healthcare						Transport							Energy					
			Aging population	Capability development	New educational products	Digitalisation	Distributed education	Aging population	Access to healthcare	Digitalisation	Precision medicine	Analytics	Healthcare business	Reduction in air pollution	Decarbonisation	Changes in demand	Mobility-as-a-Service	CAV	Digitisation	Closer coupling	Changes in demand	Decarbonisation	Decentralisation	Digitisation	Customer experience	Electrification of transport
Demand and preference driven flexible infrastructure.	▲	■	●	●	●		●	●	●				●													
Define service outcomes, capability and capacity, linked to the elements of the infrastructure and service required.	▲	■		●	●		●		●				●				●	●							●	
Commercial structures for whole system (or components within whole system).	▲	■	●	●	●		●	●	●				●	●	●	●			●		●	●				●
Socioeconomic evaluation of infrastructure/service impact and capability.	▲	■	●	●	●		●	●	●				●	●	●	●			●		●	●				●
Incentivise whole system views of supply and demand.	▲	■	●	●	●		●	●	●				●	●	●	●	●			●	●	●	●		●	●
Abstraction of actors to value creation.	▲	■			●		●		●				●				●								●	
Creation of relationships between provision, benefit, costs, risk and reward.	▲	■												●	●							●				
Infrastructure use/value-derived and charging model based on demand, environmental conditions and affordability.	▲	■															●	●					●			
Supply chain realignment based on value and creation of value chains.	▲	■															●		●				●		●	
Creation of trusted value chain to warrant the commercially relevant transfer of information (or other outcome).	▲	■															●						●			

CDBB Capability	Domain Gaps	Research Gaps	Education					Healthcare						Transport							Energy					
			Aging population	Capability development	New educational products	Digitalisation	Distributed education	Aging population	Access to healthcare	Digitalisation	Precision medicine	Analytics	Healthcare business	Reduction in air pollution	Decarbonisation	Changes in demand	Mobility-as-a-Service	CAV	Digitisation	Closer coupling	Changes in demand	Decarbonisation	Decentralisation	Digitisation	Customer experience	Electrification of transport
Risk, liability and commercial impact for asset information availability, accuracy, integrity, relevance, completeness and timing.	▲	■					●		●								●	●		●			●		●	
Awareness, training and development in an accessible and consumable form throughout the supply chain and society.	▲	■				●	●			●									●					●		
Methods to present trusted, secure, high benefit complex information and manage choice to digitally emerging or excluded members of society.	▲	■				●	●		●	●			●			●	●		●					●		
Integrated platform.																	●							●			
Creation of the data models and data sources that will underpin these systems.	▲	■				●				●							●		●					●	●		
Integration of ‘slow’ and ‘fast’ data models.		■				●				●		●							●						●		
Standards, guidelines and codes of practice for data integration.		■				●				●		●							●						●		
Data privacy and security.	▲					●	●			●	●	●	●			●			●	●			●	●	●		
Resilience of mission critical infrastructure.									●	●	●	●	●							●							
Methods to trigger and reward behavioural change.		■												●	●	●					●	●	●		●	●
Inclusion of perceptive, subjective and objective criteria into system and business models.		■					●		●								●	●					●		●	

4. Gap Analysis and capability development

This section will analyse the different perspectives on the research landscape to derive the needs for future research and capability development by the Centre for Digital Built Britain. This considers the required capability needs of UK Plc, the state-of-the-art research and stakeholder interviews.

This report has developed the findings throughout by the completion of Table 6, Table 8, Table 9 and summarised further in Table 10.

Table 10 - Summary of required capability, national themes, available research and domain requirements

CDBB Capability	Domain Gaps	Research Gaps	Number of Themes			
			Education	Healthcare	Road Transport	Energy
Demand and preference driven flexible infrastructure.	▲	■	4	3		
Define service outcomes, capability and capacity, linked to the elements of the infrastructure and service required.	▲	■	3	2	3	1
Commercial structures for whole system (or components within whole system).	▲	■	4	3	4	3
Socioeconomic evaluation of infrastructure/service impact and capability.	▲	■	4	3	4	3
Incentivise whole system views of supply and demand.	▲	■	4	3	5	5
Abstraction of actors to value creation.		■	2	2	1	1
Creation of relationships between provision, benefit, costs, risk and reward.	▲	■			2	1
Infrastructure use/value-derived and charging model based on demand, environmental conditions and affordability.	▲	■			2	1
Supply chain realignment based on value and creation of value chains.		■			2	2
Creation of trusted value chain to warrant the commercially relevant transfer of information (or other outcome).	▲	■			1	1
Risk, liability and commercial impact for asset information availability, accuracy, integrity, relevance, completeness and timing.	▲	■	1	1	3	2
Awareness, training and development in an accessible and consumable form throughout the supply chain and society.	▲	■	2	1	1	1
Methods to present trusted, secure, high benefit complex information and manage choice to digitally emerging or excluded members of society.	▲	■	2	3	3	1
Integrated platform.					1	1
Creation of the data models and data sources that will underpin these systems	▲	■	1	1	2	2
Integration of ‘slow’ and ‘fast’ data models.		■	1	1	2	2

CDBB Capability	Domain Gaps	Research Gaps	Number of Themes			
			Education	Healthcare	Road Transport	Energy
Standards, guidelines and codes of practice for data integration.		■	1	2	1	1
Data privacy and security.	▲		2	4	3	3
Resilience of mission critical infrastructure.				5	1	
Methods to trigger and reward behavioural change.		■			3	5
Inclusion of perceptive, subjective and objective criteria into system and business models.		■	1	1	2	2

Table 10 demonstrates that the 21 capabilities identified can be consolidated into four principal capability statements, detailed in the subsequent sections. These are:

- The causal relationship between the infrastructure and value of service socioeconomic outcome is defined.
- The structure, commercial value and liabilities of the information is defined.
- The supply-chain is aligned to value creation.
- Organisations have the capability and capacity to use digitally enabled methods to deliver value within the supply chain and to society.

The causal relationship between the infrastructure and value of service socioeconomic outcome is defined.

This combines the following:

- Define service outcomes, capability and capacity, linked to the elements of the infrastructure and service required.
- Socioeconomic evaluation of infrastructure/service impact and capability.
- Resilience of mission critical infrastructure.
- Inclusion of perceptive, subjective and objective criteria into system and business model.

This capability is core to all other capabilities and fundamental to creating a supply chain focussed on achieving service outcomes. It will help guide decision making, prioritisation and effort deployed to matters that make a difference. Establishing these relationships is expected to unlock all of the other capabilities discussed here and supports the discovery of new connections.

The relationships will be part of a system of systems. Care will be needed to ensure that system boundaries are clear, and causality can be established. It is inevitable that externalities will have an influence, either included as a factor in the relationship or where the magnitude is of a low order. It is anticipated a full statistical analysis of the relationships will be required along with independent audit if they are to be used in any commercial form.

The focus on the total value of the relationships in social and economic terms will help guide attention to the factors with the greatest leverage. This will guide decision making throughout the asset lifecycle from planning options, where quantitative assessment can be made, through to service design where priority can be biased towards those with greatest need. It will also provide the framework in which investment decisions can be taken and the risk and reward for the client and supply chain can be defined.

The focus has been on objective relationships; however, these are not the only relationships that exists. There is a subjective perspective which also needs to be considered as part of this capability development.

The relationships will have attributes that are key to achieve the outcomes. These require definition to provide the detail in which the relationship can be transacted. Once defined, the method and form in which the data is capture can be set and the information value chain is established.

The key elements within this capability description are:

- There is a causal link established between the service and infrastructure at varying degrees of abstraction.
- The service and infrastructure cannot be viewed in isolation. It needs to be considered as part of a broader system of systems at a degree of fidelity that is 'significant'.
- How value is defined, assigned and considered by different actors.
- The social, economic and environment relationship refers to the triple bottom line impact and benefit.
- Objective and subjective relationships are contemplated.
- The security implications of establishing relationships and creating dependencies.

The structure, commercial value and liabilities of the information is defined.

This combines the following:

- Creation of relationships between provision, benefit, costs, risk and reward.
- Infrastructure use/value-derived and charging model based on demand, environmental conditions and affordability.
- Creation of trusted value chain to warrant the commercially relevant transfer of information (or other outcome).
- Risk, liability and commercial impact for asset information availability, accuracy, integrity, relevance, completeness and timing.
- Integrated platform.
- Creation of the data models and data sources that will underpin these systems.
- Integration of 'slow' and 'fast' data models.
- Standards, guidelines and codes of practice for data integration.
- Data privacy and security.

Having defined the causal relationships and the attributes that link the asset to the outcome, this capability creates the data model with sufficient integrity and security along with the process obligations so it can be used for commercial transactions.

The core of this capability is the creation of the data model in sufficient detail that the attributes and relationships are defined. It is not anticipated that a model of everything is needed; only the elements that describe how the outcome is achieved and the interactions with adjacent systems. The existing domain models are expected to tie in to this layer, thus minimising the impact on existing work and maximising the speed of development. The layer will need standardisation if integration is to occur which will require new standards to be developed across the existing domains.

The data generated and used throughout this process must be secured and assured if it is to underpin the commercial relationships of the organisations. There is existing research on the use of distributed ledgers for the transactions and this is an option for consideration. However, the greater challenge is an organisation's ability to generate and manage data through the data lifecycle to safeguard its integrity. If data is being used for transactions, an audit and assurance process will be needed as part of data governance. Currently insurance companies are familiar with the risks associated with traditional approaches to the works and services and have products tailored for these needs. The shift to a digitally enabled transactional process will require new risks to be evaluated and data warranted. This is comparable to the governance and probity needed in the financial sector and is an area requiring further analysis.

The key elements within this capability description are:

- A cross-domain data model and standards at a level of abstraction to describe the causal relationships and attributes needed for the value chain.
- The value in the transaction is considered.
- The model is secure and trusted, with integrity aligned to the financial sector.

Supply-chain aligned to value creation

This combines the following:

- Incentivise whole system views of supply and demand.
- Abstraction of actors to value creation.

The current supply chain is organised around a range of commercial models that have developed to package work in such a manner to manage risk. This has created a system of tiered relationships where each party is primarily focussed on the output at the lowest possible cost. When the value of each stage in the supply chain is understood and the actions needed to achieve the outcome, the existing relationships are expected to change.

It is expected that rather than tiers of organisations in a supply chain, a capability to build a value network will be established. In the value network, organisations will understand and be measured on how they are adding value the outcome and will be incentivised to undertake their obligations with this consideration front and centre in all they do. This is clearly a change from the existing relationships and will make many organisations nervous who have refined their actions under existing models. If this does not happen, the value in the outcome will not be realised, due to continued inefficiencies associated with existing models.

How the new models will form is open to debate and requires further research. It is hypothesised that two main approaches are likely: a horizontal or vertical integration. With a horizontal approach along the lifecycle, actors will reform based on how the value is manifested throughout the asset creation, maintenance and beneficial use. Meanwhile, a vertical approach will see the tiered supply chain

disappear and peer-to-peer relationships develop around the nodes of value creation. It is the authors view that horizontal integration will occur where there is a close coupling of asset and service, with vertical integration possible at any stage of the lifecycle independent on the strength of coupling.

The commercial models that incentivise these relationships are required. A vertical integration is expected to be easier to establish as the timescale between action and effect is shorter, meaning any system latency can be better controlled and impact realised. However, a horizontal integration may take many years for the benefits to realise, and this time offset will need careful consideration to manage liquidity while driving outcomes and avoiding externalities.

The key elements within this capability description are:

- The definition of where the value originates.
- How to realign actors around the value creation in a structure that is commercially viable.

Organisations have the capability and capacity to use digitally enabled methods to deliver value within the supply chain and to society.

This combines the following:

- Awareness, training and development in an accessible and consumable form throughout the supply chain and society.
- Methods to present trusted, secure, high benefit complex information and manage choice to digitally emerging or excluded members of society.
- Methods to trigger and reward behavioural change.

Many organisations have embarked on a journey to digitally transform. The starting point for this journey differs for many, especially away from the large organisations who have had the need and means to invest. This means for a digitally enabled supply chain or value network to flourish there is work to do to build a capacity of capability in the industry, especially at lower tiers in the existing supply chain.

BIM has helped in the design and build part of the supply chain, and computer aided facilities management provided an insight into fault management during maintenance. However, this is just a start if the true value is to be realised. BIM is now becoming common place at the higher tiers in the existing supply chain, but once it reaches the tiers where most of the value is added, the use of the digital information is minimal in many cases.

In maintenance, asset management systems or computer aided facility management are often used for inventory and works orders. Very little additional value is created, and the base data quality is variable.

For digitally enabled services to be adopted there is a notable capability development to be addressed. At an organisational level, whether this is government or private sector, the general level of digital maturity is emergent from both the perspective of service design and application. The design of digitally enabled services is a new skill that is being developed across the country and will be core to achieving adoption. While central government has invested heavily in the Government Digital Services (GDS) activity, the same level of investment has not always been possible away from Whitehall. This can result in services that are difficult to use for the most IT literate people and prove to be a stubborn barrier for others.

How people access services is changing with advancement in technology. Capability development needs to ensure inclusion, not gentrification, of new services is achieved with the technology and attention is given to those most in need or vulnerable. The capability needs to consider end-to-end service design, the relationship with the technology stack, and the infrastructure.

The technology market will need to listen to the needs of the digitally enabled service designers and prospective users, and be informed by them. This will include how to provide digitally enabled services to those who are not digitally enabled and would be benefitted the most.

There will be a large amount of data used and information developed with the new services. The provision of just the information needed to decide, in a contextual and consumable form, will be key to adoption and therefore impact. The determination of relevance to an individual and a context is another area for exploration. Here, preferences will need to be determined with the context of the information provided, at a point in time, at a location, on the basis of other service information and informed by previous choices. This will require simplification to provide just that which is relevant and is key to the decision-making process.

Overall, it can be seen that step changes have occurred, with greater steps needed if the true value of a digital supply chain is to be realised.

The key elements within the capability description are:

- How to build and building digital capability across society.
- How to build and building digital capability throughout the supply chain.
- Development of end-to-end full stack services.
- How to serve contextual information in a consumable form.
- Development of decision support tools.
- How to provide digitally enabled services to those who are digitally emerging or digitally devoid.

5. Demonstrators

This section will give examples of the principal supply chain arrangements seen in the built environment throughout the asset lifecycle. These examples will focus on the service operation, rather than an exhaustive analysis of design and build contract forms. This approach has been taken as the supply chain will coalesce around the form of agreement. The aim is to demonstrate where there is capability within the market and to identify where further work is needed.

Professional Services

Professional Service Agreements are commonly used for the provision of architectural, engineering or consultancy services during the planning and design stage of the contract. Often due to the evolving nature of the brief, the work is contracted on a time and materials basis which drives a reputation or behaviour of prolongation, rather than standardisation and outcomes.

Build

With a build contract, the contractor will receive all of the design information, normally priced against a bill of quantities. The contractor is incentivised to build the scheme as fast and as cheaply as possible to meet the brief, while seeking opportunities for change that increase scope and profit. This type of contract is frequently fixed price for a scope of works. Examples of these contracts are where the design is well defined, the risk profile understood and where there is a scale of capability in the market to drive competitiveness.

Design and Build

To mitigate the risk of change, design and build contracts were developed. Here, once the design is matured to an outline level, the design is novated to the contractor who works with the designer to develop a buildable solution. These contracts can be single or two stage, fixed price, bill of quantities and fee, activity based, or target cost. These contracts commonly arise when there is a degree of uncertainty about the design, which requires expert involvement in the development for contractors to accept the risk.

Maintain

Maintenance Agreements are used where a client or a client's representative contracts directly or through a tiered supply chain for the provision of services (and normally small works) to enable the asset availability. These agreements range from break-fix, periodic/routine, condition based and finally, risk based, in the pursuit of an available asset. The nature of the agreement depends on the client's appetite for risk to accept downtime and disruption if an asset is unavailable. This is balanced with the service provider's ability to understand the asset condition and the freedom to make interventions to mitigate the risk of performance degradation.

With buildings, these contracts are frequently held by facility maintenance companies acting as the client's agent with a supply chain below. A combination of poor knowledge of the asset and its condition, along with the frequency of re-tendering, often leads to activity-based time charge rather than outcome-based that drives effectiveness. With complex assets the agreement term is normally longer and knowledge base greater, which enables progressive approaches to risk and reward through availability to be considered.

Design, Build and Maintain

This agreement, along with design, build, maintain and operate is used where finance for the scheme is available and the client does not need to be party to any agreement to either secure its outcomes or exercise any powers they may have.

The agreement is designed to create an environment where a long-term perspective is taken with design decisions and the workmanship during construction. It is a good method for the client to mitigate their longer-term risk and provides a level of surety for the parties involved in the agreement.

With some unenlightened clients or client's agents, these agreements are in two parts, a traditional design and build, alongside a separate maintain contract. These are used where the client wishes to protect their ability to switch providers in case of underperformance or a cost benefit, yet they tend to drive behaviours to optimise for the certainty available with an eye to the future, rather than taking a true long-term perspective.

An example of this agreement would be a complex system integration such as the baggage handling system in an airport, where the complexity of the asset within the context of the airport physical and IT systems limits the number of providers that could be used, especially in the period post build.

Design, Build, Maintain and Operate

This agreement develops the DBM contract further with the operation of the service becoming part of the agreement. The disciplines required to provide all of the works and services for this scope of work is broad. Even if a single organisation holds the head contract, it is likely there are subsidiaries with different P&Ls involved in the agreement. It is more typical to form a partnership in the form of a JV, SPV or alliance to access capability, manage the risk and access a proportionate share of any up- or downside. The client maintains ownership of the asset and a lease agreement is required for the operation of the asset for the service.

This is similar to a DMFO agreement, with the exception that the project finance is provided by others or the client themselves. There has been a return to this form of late, as a consequence of high-profile excessive financing fees levied.

Design, Build, Maintain and Finance (DBMF)

This type of agreement is used where the asset will be financed, constructed and maintained for a period with another party - either the client or through a separate agreement with the client to use in the provision of a service. The ownership can be either with the service provider or with an end client who then provides lease and access agreements to the parties to the head agreement. It is primarily a method of a client accessing project finance for a scheme whereby there is an obligation on the constructor to maintain the asset. This promotes a longer-term view of the design and build process.

This is the typical approach used for the provision of a new asset where the end client does not need or has a preference not to be a party to the agreement. For example, where existing assets or statutory instruments are not required for the scheme.

Design, Build, maintain, Finance and Operate (DBFO)

The key element of this form of agreement is that the parties are responsible for the provision of the service and achieving the service outcomes on behalf of the client, who maintains title with a lease for the use of the asset assigned. This contract form is often confused with the DBMF form, where the operation is seen as the operation of the asset rather than the operation of the service. In this form the service provider is party to the agreement. It should also not be confused with the BOOT form, where ownership of the asset is held by the parties to the agreement and transferred back to the client after term. In both cases, the key factor is parties to the agreement are operating the service on behalf of the alliance.

DBFO agreements are typically structured around a number of parties forming an SPV for the direct purpose of undertaking the obligations of agreement. It is a separate legal entity with equity held by the participants proportional to their contribution in effort, funding or risk. The up- and down-side is normally shared proportional to the equity assignment.

The supply chain involved in the discreet elements at each stage of the asset lifecycle can be contracted by a variety of means, from traditional works or services agreements directly or through a framework.

Examples of this type of agreement are the PFI contracts used for a new prison estate where a combination of build and improvement actions alongside facilities maintenance is included as part of a long-term agreement for the operation of the service. There are pilot schemes for Peterborough and Doncaster that use the Payment by Results[134] mechanism based on reoffending rates.

Build, Operate, Own and Transfer (BOOT) (Design, build, maintain, finance, operate and Own)

A BOOT agreement is similar to the DBFO, with the exception that ownership sits with the parties to the agreement and transferred back to the client after term. It is normally initiated by government and used for the development of a particular section of a network or infrastructure. It is usual for the government to be a party to the BOOT agreement through the provision of land or the ability to execute a statute. If this is not needed a PPP would be frequently used.

Example of a BOOT agreement is for new hospital build such as Southmead in Bristol, whereby the Health Care Trust is a party to the agreement with the developer, maintainer and financier[135][136].

Build, Own and Transfer (BOT) (Design, build, maintain, finance, Own and Transfer)

A BOT agreement is similar to the BOOT, except the operation of the asset is by another party who is subject to another agreement. This type of agreement is used where the asset will be provided and maintained for another party to use in the provision of a service. The nature of the agreement necessitates a variety of lease and access agreements developed between the parties.

An example of this agreement is for the provision and maintenance of new rolling stock for the Department for Transport, who then have a separate franchise arrangement for the operation of the service. The Thameslink Rolling Stock Programme used this approach and resulted in the arrangement shown in Figure 11. The supply chain serving the parties to the agreement, such as the depot build, were procured under a Design and Build, as they had neither a stake nor involvement in the provision of an available train for service.

[134] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/676711/crc-nps-final-interim-results-bulletin-jan18.pdf
[135] https://www.lloydsbankcommercial.com/Southmead-Hospital-PFI/
[136] https://www.hicl.com/portfolio/case-studies/southmead-hospital-uk

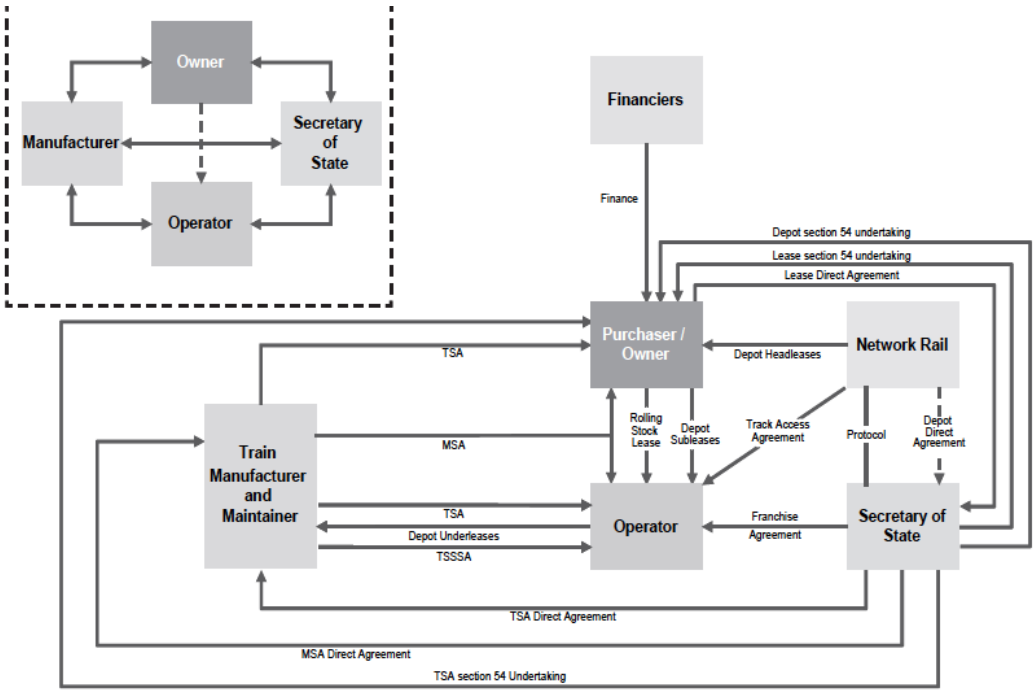

Figure 11 - Contractual structure for the Thameslink Roiling Stock Programme

Maintain and operate

A maintain and operate agreement is used where there is a close coupling of the asset and the operation, and the operator has a vested interest in ensuring the asset is available. An example of this is where Network Rail is in an alliance on both the ScotRail and South Western Railway franchises. These are chosen as there is close geographical alignment between the franchise and the infrastructure route which enables Network Rail and the operator to have closer integration of the maintenance or renewal activities and the operational service. The maintenance and renewal activities do not form part of the alliance as they are let under separate frameworks or direct contracts. This approach is more difficult with some of the other seven routes[137] as they are currently defined.

Discussion

All of the agreements have a place and purpose in the market. It depends on what the client wishes to achieve with the agreement and how these fit within the overall context of the organisation. Here lies the first challenge, in that the end state and what good looks like needs to be understood and agreed. It is the authors experience, supported by the literature review and domain review, that this is not always understood, agreed or articulated to an extent that innovation within the agreement can be achieved. Rather, there is a tendency to revert to what is known, with packaging along traditional boundaries, and focus on ill-defined outputs rather than specifics linked to objectives or outcomes.

In many cases, even the largest organisations cannot or lack the appetite to hold the entirety of a head contract. There are many specialists involved in all stages of the lifecycle, whether this is a geotechnical expert or a service provider who partners with a constructor. Traditionally they form a supply chain with a series of separate agreements between the different parties involved in the fulfilment of the works and services. For this to work, the requirements need to be understood and

[137] https://www.networkrail.co.uk/running-the-railway/our-routes/

meshed together throughout. The reality is there are always gaps in scope or responsibility, cost is always an issue with parties seeking to maximise their own position, inefficiencies created through lack of trust and definition which leads to poor behaviours, and a compromised end state. This is particularly challenging where the environment is complex and there is an emerging understanding of scope.

Alliances

An alliance is an approach to forming an arrangement where these challenges are best addressed by a number of parties with shared values and behaviours, incentivised for the parties to work together with collective risk and reward. Where risk and reward are not shared and parties work together in collaboration, this is a partnership. These are general terms to describe a collaborative management approach that encourages openness and trust between parties to a contract. The parties become dependent on one another for success, and this requires a change in culture, attitude and procedures throughout the supply chain.

Alliancing can be adopted for a one-off project or can be a long-term relationship over a number of projects (such as a framework agreement). The longer the contract, the greater the benefit of partnering as there is more opportunity for building working relationships, finding improvements and planning investment. Successful alliancing should enable long-term integration of the entire project team for the mutual benefit of all, and so it is crucial that the right partners are selected. The commercial objectives and culture should be aligned throughout the alliance, the use of parties' resources should be optimised and risks should be allocated to those most able to mitigate them.

It takes expertise and commitment from the client to set up and manage the process effectively and adjudicate disputes with alternative dispute resolution. Thus an Alliance Agreement can be arranged either by use of a traditional contract with a separate partnering agreement, or by use of a contract with an aligned partnering agreement. It can be either a two-party or multi-party arrangement. Where the client is part of the alliance the greatest benefits can be achieved, as they are best able and incentivised to support development of a successful outcome.

The key elements of a successful alliance have been researched for some time by many, including Larson[138], Bruce[139], Mohr[140], Tsosvold[141] and Spekman[142]. These insights and those of many others over the years, are described by P13[143] as:

> Alignment: The commercial performance measures are aligned to delivery of outcomes to the customer/end user. This ensures all partners work collectively in the best interests of the end user rather than introducing commercial tension across contracts.
>
> Reward: The reward mechanisms in the enterprise structure are based on value added in exceeding the outcomes, not competing for the lowest cost for a component. This way each party

[138] Larson, Andrea, "Partner Networks: Leveraging External Ties to Improve Entrepreneurial Performance" in Journal of Business Venturing, Vol.6, No.3, pp173-188, May 1991
[139] Bruce, Gregory and Shermer, Richard "Strategic Partnerships, Alliances used to Find Ways to Cut Costs" in Oil & Gas Journal, pp14,71,74,76, November 8, 1993
[140] Mohr, Jakki and Spekman, Robert, "Characteristics of Partnership Success: Partnership Attributes, Communication Behavior, and Conflict Resolution Techniques" in Strategic Management Journal, Vol.15, pp135-152, 1994
[141] Tjosvold, Dean, Team Organisation: An Enduring Competitive Advantage, Wiley, England, p46, 1991
[142] Spekman, Robert E. and Sawhney, Kirti, Toward a Conceptual Understanding of the Antecedents of Strategic Alliances, Marketing Science Institute, Cambridge, Massachusetts, USA, p6-7, 1990
[143] http://www.p13.org.uk/wp-content/uploads/2018/06/P13-Commercial-Handbook-Web.pdf

shares the interface risk between organisations and also ensures reward is linked to a quality performance rather than volume of work/hours put in.

Risk: Risks that the owner or investor are accountable for are not transferred to the supply chain. Instead all parties in the enterprise are given incentives and potential reward based on their ability to mitigate the risks.

Engagement: The enterprise comes together at a much earlier stage in the asset enhancement/creation lifecycle. Shortly after the need has been identified the owner will engage the integrator. This allows for the pooling of knowledge, expertise and application of innovative solutions in solving the problem.

Scale: The enterprise model yields the greatest benefits when applied across asset networks, not just small-scale individual projects or to deliver component parts of programmes.

Time: The relationships between organisations last over a longer time period, incentivising investment in skills and tailoring of supply-chain business models. This, combined with asset network level scope, will improve productivity through changes to ways of working, enabling innovations that require long-term commitment for payback such as delivery methods like offsite construction.

The degree in which the client and the organisations commit to the alliance does vary. This has prompted the adoption of the terms 'shallow or deep' for alliances in the industry, with the depth of integration depending a variety of factors, including the commercial model and the need to combine capability to provide a service. The advent of the NEC4 alliance suite of contracts will hopefully prompt more organisations to adopt this approach. Examples of alliances available in the public domain include:

Design and Build

True alliances, where risk and reward are shared by the parties within infrastructure, are most common in the design and build part of the lifecycle at the moment. Examples of these alliances include:

Anglian Water: @One Alliance[144]. This has been widely acknowledged as the industry exemplar for alliancing. Parties to the alliance include: Anglian Water, Balfour Beaty, Barhale, Mott MacDonald, Bentley, Stantec, Skanska and Sweco.

Network Rail: East West Rail Alliance. This is the design and construction of the East-West Rail project Phase 2. Parties to the alliance are: Network Rail, Atkins, Laing O'Rourke and VolkerRail.

Highways England: Smart Motorways Alliance[145]. This is currently being procured.

London Borough of Hackney and London Borough of Haringey: Supply Chain Management Group. A two client, multi-contractor alliance[146] with Mulalley, Keepmoat, Mansell, Lakehouse, Lovell and Wates for a £221m housing programme.

[144] http://onealliance.co.uk
[145] http://assets.highwaysengland.co.uk/specialist-information/smart+motorway+alliance/SMA+Descriptive+Document.pdf
[146] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/325951/SCMG_Trial_Projects_Case_Study__CE_format__130614.pdf

Design, Build, Finance and Operate

Highways England has used DBFO[147] contracts since 1994 to access private capital to address public infrastructure needs. There are 11 DBFO agreements in place as follows: A1 Darrington to Dishforth, A1(M) Alconbury to Peterborough, A19 Dishforth to Tyne Tunnel, A249 Stockbury (M2) to Sheerness, A30 Exeter to Bere Regis, A419 Swindon to Gloucester, A50 Stoke to Derby Link, A69 Carlisle to Newcastle, M1 Lofthouse to Bramham Link Road and M40 Denham to Warwick. The most well-known is Connect Plus[148], a 30-year consortium with Balfour Beatty, Egis Road Operation UK and Edge Orbital Holdings for the design, build, maintain, finance and operation of the M25. Although these are consortia rather than deep alliances, they do sit on the spectrum of alliances.

Maintain and Operate

Network Rail operates in an alliance with the current franchise for ScotRail[149] with Abellio and South Western Railway[150] with MTR. This is defined[151] as an alliance where one of Network Rail's routes (or potentially part of a route) and a train operator share upside and/or downside risk against an agreed baseline for all or most of their activities. In Network Rail's view, this is only appropriate where an operator has a very strong geographic alignment with the route – such that it has very little traffic on other routes and other operators have a small proportion on the route in question. This enables Network Rail and the operator to have closer integration of the maintenance or renewal activities and the operational service. The maintenance and renewal activities do not form part of the alliance as they are let under separate frameworks or direct contracts.

Capability Development

The research has indicated there are pockets of excellence where clients and the highest tier of the supply chain have formed a contractual-based working relationship in which uncertainty is managed in a cooperative manner and all parties are incentivised to perform. Currently this is concentrated around the design and build part of the lifecycle where the market feedback is generally good, alongside maintain and operate where there is a close coupling between the asset and operation performance. Examples of a broader design, build, finance and operate model with a consortium providing a PPP/PFI frequently has sub-contracts to the various partners for their element of scope, as opposed to a deep alliance with shared outcomes and aligned reward. These models are often focussed around the financial structure of the deal and the clear assignment of responsibilities alongside a commitment to collaborate and work in partnership.

In all examples the depth of integration of the second or third tier supply chain or creation of a supply network is absent. The feedback from the domain review suggested the market needs more time to understand how to create these alliance relationships, how to align objectives, value and outcomes,

[147] https://webarchive.nationalarchives.gov.uk/20140603114609/http://www.highways.gov.uk/our-road-network/managing-our-roads/operating-our-network/how-we-manage-our-roads/private-finance-initiatives-design-build-finance-and-operate-dbfo/
[148] https://www.connectplusm25.co.uk/connectplus/
[149] https://cdn.networkrail.co.uk/wp-content/uploads/2017/01/Alliance-Framework-Agreement-Abellio-ScotRail-Limited-Redacted.pdf
[150] https://cdn.networkrail.co.uk/wp-content/uploads/2017/01/Alliance-agreement-Wessex-Route-and-SSWT-franchise-services-redacted.pdf
[151] https://cdn.networkrail.co.uk/wp-content/uploads/2017/01/Alliancing-Network-Rail-policy-statement.pdf

how to link these to proportionate risk and reward, and to develop capability and capacity within the market to create these entities.

There is no question that information is a fundamental part of creating these new alliances and building a supply network to deliver efficiencies and effectiveness. It provides transparency, underpins accountability and enables new business transactions to be developed. Building Information Modelling has been an enormous step in the industry providing a process of what information is required about the asset primarily from construction to handover. However, as this review has demonstrated, the broader understanding of what is the key information needed throughout the entire lifecycle and how to manage this to leverage value is absent.

6. Conclusions

The assets within the built environment contribute to over £600bn of value each year to the UK economy, with millions of people and thousands of companies involved in this value creation. The sector is complex, diverse, fragmented and under tremendous pressure to improve productivity and remain financially viable and stable.

The supply chain has remained largely unchanged for many years, while the world has moved on with different needs and expectations emerging at a time where the use of digital techniques is revolutionising every other sector in the UK. The authors urge caution to suggest that digital techniques alone will transform the sector, but they can be an enabler if correctly adopted.

This report has identified 18 themes across diverse sectors of education, healthcare, transport and energy in the time horizon 2040-2050. These will require 21 capabilities to be developed, ranging from defining causal relationships from assets to service outcomes, through to identifying where value is enabled throughout the lifecycle. The state-of-the-art for these capabilities demonstrated the digital enabled supply chains for the manufacturing sector were well understood, but there is very little research available for service and service reliant on the built environment. The research that is available cited the importance of information to underpin the development of new delivery models. The new delivery models suggested focus on the development of value networks coalesced around outcomes rather than the classical supply chain we have today. Since the supply chains tend to form around the contractual arrangements, the contractual arrangements currently used were analysed. This illustrated a number of the challenges and opportunities that exist when defining outcomes and the factors to be considered in their determination.

The universities or other institutions working in this area of capability development is very limited. There is research in adjacent areas that may be leveraged, but this has highlighted a research gap that needs addressing if the required capabilities are to be developed within the time horizon.

A series of stakeholder interviews were conducted across the different sectors. The interviews were conducted under the Chatham House Rule for expediency and in order to get an honest opinion, and avoiding approvals required from government or other organisations. The participants included in the market engagement included regulators, government, infrastructure creators, system operators and service providers. The principal observations of this engagement were:

- A greater understanding of the problem to be addressed requires defining to avoid following over-hyped trends.
- The concept of outcome-based contracts and delivering value are understood as concepts, but the challenge of defining an outcome in terms that can be contracted and monetised was foreseen.
- Those participants who had experience of outcome-based contracting noted the need for simplicity.
- There is an agreement that some assets are closely coupled to the service and others are not. Focus should shift to those scenarios where a close coupling exists, the outcome articulated, and the value leveraged.
- There is an appetite to accept the risk of outcome achievement, if it is balanced with sufficient reward.
- It is recognised that data is fundamental to achieving these new capabilities and data governance is essential.

21 capabilities were identified when the future needs of the UK are considered, alongside the state-of-the-art knowledge in these areas. These reflect the current capability of the market. These capabilities have been consolidated into four principal capabilities that need development for the UK to respond to the requirements in the time period 2040-2050, and are as follows:

- The causal relationship between the infrastructure and value of service socioeconomic outcome is defined. This capability will enable the attributes of an asset, which support the creation of value of the outcome, to be identified and traced though the lifecycle.
- The structure, commercial value and ,is defined. This capability creates the data model with sufficient integrity and security along with the process obligations that mean it can be used for commercial transactions.
- Supply-chain aligned to value creation. This capability identifies the networks of value creation and will identify a new landscape for a supply chain focussed on delivering outcomes.
- Organisations have the capability and capacity to use digitally enabled methods to deliver value within the supply chain and to society. This capability will provide the capacity of skills and competence necessary to define, use and benefit from the digital techniques in the supply chain.

There are not any demonstrators currently attributed to these capabilities. Therefore, the research looked to where contractual relationships have been established throughout the asset lifecycle to see how a data driven approach to the supply chain has realised service value. This illustrated that an alliance approach, where the parties are aligned and work together to achieve shared outcomes with a proportionate risk and reward, would be the ideal arrangement. The alliances identified are focussed on discreet areas of the supply chain like design and build, or maintain and operate, rather than an end-to-end approach at this stage.

In summary, the research landscape and future capabilities needed by government, by those involved in the specification, design and delivery of built assets and across a portfolio of services, through-life, for businesses and citizens have been demonstrated. In addition, the capabilities needed by government, business and citizens to best derive value have also been established, as well as how such operations will be managed and enabled within specific supply chains, how organisations will work together, how services will interact with the built environment. While there is some knowledge in existence, this is an emerging area of research that would continue to support the UK in developing a commanding position and lead the world in digitally enabled value creation within the built environment.

7. Recommendations

In order to develop the national capability needed to make a digitally enabled supply chain work and address the needs on a time horizon of 2040-2050, it is recommended the Centre for Digital Built Britain takes the following actions:

1. Accelerate current and future high value use cases

This subject is heavily dependent on the commercial arrangement of the supply chain. While theoretical assessment and recommendations can be made, it is often only when there are live examples do the real challenges surface and innovation emerges. This is also chicken-and-egg: the commercial organisations will not deploy new approaches without confidence of success. Therefore:

a) It is recommended that a high value use case is identified from the current portfolio of contracts that transcend all stages of the lifecycle and a 'shadow' structure is developed in combination with the existing parties to create a parallel digitally enabled value network. This digitally enabled value network would need all of the components a 'live' version would need: causal relationships, attribution, data model, value nodes and so on, albeit probably as a thin slice and with pseudo integration. The network should then run in parallel for a demonstrable period to learn lessons, refine the core network components and directly research. This would provide the basis for the second part of the recommendation for a future high value use case.

b) It is anticipated that any of the emerging as-a-service business models with a close coupling between the asset and the outcome would be an ideal candidate, for example, mobility or energy. It is considered a prerequisite for these as-Service models to have a digitally enabled value network, otherwise it will be difficult to establish and contract the basic relationships that form the foundation of the service and successfully scale-up. Building on the parallel running and component development in (a), this would allow the development of the digitally enabled value network in anticipation of future deployment.

It is noted that both parts of the recommendation would probably need a funding competition run to comply with procurement rules.

2. Initiate collaborative research

There is very little existing research in this area, and it does not naturally align to traditional definitions of schools or departments. The research needed sits at the intersection of engineering, law, humanities and the business school, and will need all of this expertise to collaborate if the fundamental and applied questions are to be answered. These being:

- Understanding loose and close coupling of assets and service outcomes.
- Identifying where value is created in closely coupled assets and service provision.
- Defining the causal relationship between the infrastructure attributes and value of service socioeconomic outcomes.
- Creating the data structure and determining commercial value and liabilities of the information value chain.
- Creation of the legal principles for value network.
- Determining the behaviours required for the digitally enabled value network to flourish.

3. Support capability development

A move to a digitally enabled value network will require support if the capabilities needed with clients, supply chains and places of learning are to be established in sufficient quantities to make this approach viable. For example:

- Standards, guidelines and codes of practice: new standards, guidelines and codes of practice will be required to describe the data structure and interfaces between domains.
- Training: the industry is well schooled on current practices. New methods will require development from a technical, commercial and behavioural perspective.
- Exemplars: once examples are established, it is essential to show ‘what good looks like’ and to share lessons learned to build advocacy and confidence.
- Networks: it is proposed to leverage the existing networks and privileged position that CDBB enjoys build advocacy and create a network of practitioners with their own unique experiences to build upon.

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