Strategic Outline Business Case for the delivery of Digital Built Britain Programme Level 3

Digital enabled transformation of the full lifecycle of the built environment to increase productivity, improving economic and social outcomes.

Building a better working world

This strategic outline business case (SOBC) sets out the case for investment in Level 3 of the Digital Built Britain Programme in accordance with the HM Treasury Green Book guidance

Developed by:

EY
Building a better working world

In collaboration with:

Department for Business, Energy & Industrial Strategy

Innovate UK

University of Cambridge

IfM Education and Consultancy Services

Catapult Future Cities

VisualMeaning

Foreword

"In 2015 the government set out its visionary plan for a Digital Built Britain. By digitising the entire lifecycle of the UK's built assets it will reduce whole-life costs and carbon while ensuring availability and resilience of infrastructure. To enable the programme, a £15m delivery partnership was formed between Innovate UK and the Department for Business Energy and Industrial Strategy (BEIS) to focus on:

- British standards and support for building information modelling (BIM) Level 2
- increased international trade opportunities for UK companies
- development of BIM Level 3 programme
- cyber security
- private sector investment and engagement
- early adopter projects focusing on BIM Level 3A and manufacturing technologies

This strategic outline business case sets out the investment case for the development of a Digital Built Britain. It demonstrates the significant impact of the built environment on the UK's economy and its potential to increase the UK gross domestic product (GDP) over the next 15 years.
I would like to express my thanks and gratitude to all those who contributed and to recommend this business case to the many innovative start-ups and SMEs who are transforming our great industry.

This business case sits at the heart of the £170 million Transforming Construction Industrial Strategy Challenge Fund (ISCF) programme and the aligned sector deal which will seek to deliver this vision to revolutionise the productivity of the construction sector for future generations."

Simon Hart, MIET
Management Officer, Digital Built Britain

Executive Summary

This document summarises the case for government investment in the development of information standards, tools and skills to enable a greater economic and social return from how central and local government expenditure is invested in UK infrastructure.

Such an investment enables improvement in how the UK's infrastructure is planned, designed, constructed, managed and operated, delivering more output, at lower cost and with a greater level of resilience. This proposal is presented as a Green Book business case, which sets out in 5 'cases' the strategic, economic, financial, commercial and management rationale for action, and sets out a range of options by which the required outcome might be achieved.

This is presented at a time when government is making record levels of investment in new transport, energy, utilities, education, housing, health and defence infrastructure through the National Infrastructure Delivery Plan 2016-2021 (NIDP). Despite huge advances in the application of information and technology, the way existing infrastructure is operated and exploited has changed very little over past decades. The UK must not only build new infrastructure but also make sure that what already exists works as effectively as possible.

Limitations of existing infrastructure are in evidence almost every single day, with the productivity potential of the UK limited by overcrowded or congested transport links; insufficient affordable housing with convenient access to centres of employment; overburdened healthcare services; a growing shortage of schools; inadequacies in localised energy supply and a need for greater resilience to the extremes of changing weather patterns.

In many cases, much of the required capacity to achieve the desired outcomes already exists, but a joined-up means of reallocating and reconfiguring multiple existing infrastructure services to release that latent capacity does not.

In the past 6 years Digital Built Britain (DBB), formerly the UK BIM Task Group, developed Level 2 BIM with the goal of improving productivity and realising greater efficiency in the UK's construction sector. The UK has led the international field and has grown architectural, engineering, construction and information services exports as a result. In 2015 the Cabinet Office reported[1] the application of Level 2 BIM standards, tools and skills has already helped save £2.2 billion across government.

DBB's scope was extended in February 2016 beyond construction efficiency to include information to support the growth of our current and future cities. The prize has grown too, from improving construction efficiency, to improving national productivity through ensuring built and natural assets provide high performing services.

A next generation of DBB (Level 3) is required to support information throughout the whole economic lifecycle of built environment assets. Work undertaken in the production of this strategy has identified the relationships and potential value that could be unlocked if such a holistic, evidence based approach was taken. Figure 1 illustrates the end-to-end value chain and potential value which could be unlocked by the DBB programme.

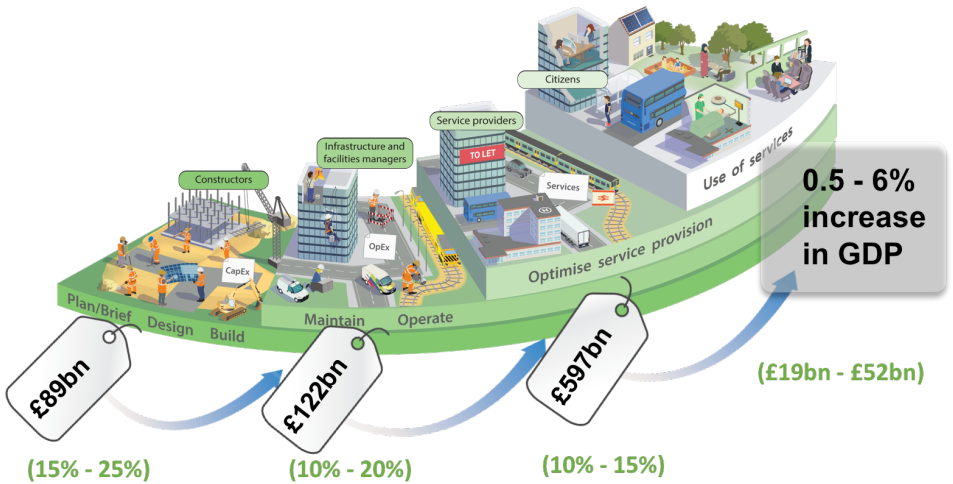


Figure 1 – Whole lifecycle potential benefits of DBB can unlock 0.5-6% of GDP

In 2016, the built environment had an impact of approximately £808 billion on the UK economy, which is around 43% of GDP. This impact occurs throughout the asset lifecycle as illustrated in Figure 1. There was £89 billion of spend in the Capital Expenditure phase through planning, design and build. This spend increases to £122 billion during operations and maintenance, with the economic output, functional services, reliant on the built environment amounting £597 billion.

On the basis of the successful work already carried out by DBB and on the evidence of interviews with potential beneficiaries, backed by case studies that provide benchmarks for isolated examples of information application, benefits at each stage of the lifecycle are anticipated. This shows that DBB presents the opportunity to unlock a 0.5 - 0.7% increase in annual GDP over the coming 5 years, rising to 1.0 - 2.7% over the subsequent 10 years, growing to 3 - 6 % after 15 years. These gains could not otherwise economically be realised in the absence of the right information standards, tools and skills.

The DBB approach will continue to develop the interventions for individual capital expenditure (CapEx), operational expenditure (OpEx) and service outcomes, including further investment to that already made in Level 2 BIM and enablers to construction efficiency modular manufacturing, design management, robotics, new materials and analytics. However, as we have seen with past investments such as Level 2 BIM, such narrow scope interventions can only by definition have limited impact. The learning from Level 2 has been invaluable both in terms of return and learning but it will be the last intervention into the “old model” we will make. Going forward it is clear we need a “new model” and the digitisation of the sector as proposed by DBB will provide the digital platform for a full cross integration of the built environment service sector.

Digitisation will enable CapEx, OpEx and service outcomes to systematically learn from each other. The feed-forward of information from construction to operations and service provision allows for assets and asset systems to operate for less cost and services to be optimised. The feedback of information of how infrastructure is used and how it performs allows for improved planning, briefing and design, construction and operation/maintenance approaches. An open transparent platform will enable the government, the service industries and the public, the ultimate consumer of the services, to understand how public money is spent and how value is ensured.

Leaving this intervention to the market will take too long, if it happens at all. DBB’s work on BIM L2 has already demonstrated on the international stage that when government primes new information standards, skills and tools, the market for services and significant benefits follow.

The SOBC concludes, through the 5 cases of the green book approach:

Strategic case: there is a strong case for change. The previous work of DBB has proved the validity of the approach. The SOBC work has confirmed its wider applicability and overall link to improved productivity in a way that enables the innovation, skills, infrastructure, procurement, energy and regional growth pillars of the Industrial Strategy Green Paper.

Economic case: the economic return makes investment worthwhile. There is an opportunity to make changes in government-funded capital spend that benefit the long-run operating costs of an asset. This will improve operations on existing assets that benefit services outcomes and to optimise services dependent upon government-funded infrastructure to meet demand. These benefits are amplified when modelled across multiple services such as housing and transport, translating to a quantified and improved social value. The return cannot be achieved without government support to prime the market. Options for intervention have been identified, and will be further developed as the programme progresses.

Commercial case: DBB would grow the UK’s existing information-related skills and services market as a world-leader with export potential. The SOBC has identified a gap in the market for new commercial services in the provision of infrastructure optimisation and investment modelling, dependent upon successful adoption of an information standard. The previous work of DBB has already proven this to be the case in construction, with UK firms leading the way.

Financial case: DBB’s work would be a key enabler for realising the objectives of both the Construction and Smart City themes within the Industrial Strategy. The early stage work of DBB to prime the market is best delivered through research and development funding associated with the Industrial Strategy, directed into a centre of excellence that attracts private sector investment.

Mangaement case: DBB’s work requires continuation of a Green Book approach, combined with the DBB programme’s System Engineering approach to implementation. This will provide a clear alignment between the overall policy

objectives of government, sectors and beneficiaries, the development of a private sector commercial services market, information standards, skills and tools, required sensing and monitoring technology; all wrapped in a security and trust framework.

Recommendations:

The recommended next steps for the DBB programme are:

1. Short-list the preferred Level 3 option for further development during an outline business case. This could include further development around these themes:
    a. Engagement with industry, government and academia to inform and challenge
    b. Development of a research bridgehead
    c. Identify the necessary standards, tools and skills
    d. How product and service certification could be achieved, for example with an equivalent to ‘RegTech’
    e. Integration with the other aspects of the DBB programme, including manufacturing
    f. Development of Proof of Concepts and Pilots.
2. Seek funding to develop a short-term Level 2 (Convergence) programme to leverage the investments made in BIM, sensors and measurement and digital city services
3. Determine the best manner in which the preferred option can be further developed and delivered
4. Communicate progress regularly and engage with industry, government and academia to ensure a managed industry change process

Table of Contents

Table of Figures

Table of Tables

1. Introduction

Whilst there are innovative businesses across the UK, a considerable productivity challenge persists. Figure 2 shows the UK's productivity is lagging an average 20% behind the economies of France, Germany and the US[2]. This currently stands at 20% of the total GDP of £1,869 billion. Even though considerable effort is made to close the gap, each time there is an economic recession the gap widens due to different approaches taken by each country. This was particularly prevalent after the 2008 market crash when many countries invested significant amounts of public expenditure into infrastructure. Productivity within the UK construction sector is further behind the national average and due to its impact on the overall country GDP, will hinder the country's economic performance. This is a result of a multitude of factors including slow adoption of innovative processes and technologies, high labour intensity, limited coordination and unsophisticated supply-chain practices.

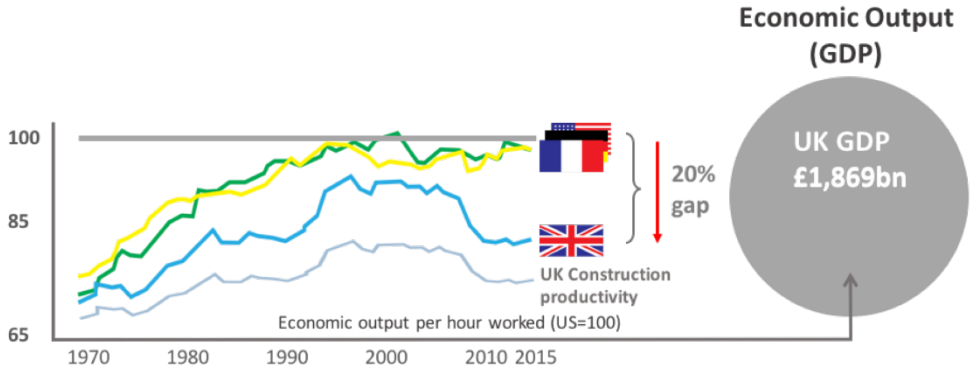


Figure 2 - Economic growth/hours worked: the widening productivity gap over 50 years

In 2011, the Government Construction Strategy mandated the use of Level 2 BIM on all central government-funded projects by 2016. Level 2 BIM is changing the UK construction industry – a vitally important sector that employs more than 3 million people and in 2016 delivered £89 billion to the UK economy[3]. BIM Level 2 enables cooperation using an information model of the built asset and enables the coordination of the information about the design, construction, and hands-over to operation/maintenance of that asset.

At the design stage, Level 2 BIM has enabled multi-disciplinary project teams to more efficiently and effectively create designs and to test them before they are built, resulting in the elimination of service 'collisions' requiring design re-work and causing costly delays.

In construction, Level 2 BIM has enabled engineers, contractors and suppliers to plan the sequencing of the construction process and plan the integration of complex components, reducing waste and risk of re-work.

Level 2 BIM has enabled efficiencies through the co-operative use of shared construction project information models and has been a significant contributor to construction cost savings over the last 5 years. The application of Level 2 BIM has realised efficiencies of between 10 and 20%[4] [5] [6] in the capital investment phase of the built environment economic lifecycle. The Cabinet Office construction reports have also indicated that during 2011 - 2015 Level 2 BIM yielded over £2bn[7] of savings on government projects.

This DBB programme brings together the Industrial Strategy, including the Construction 2025 Strategy[8], the Business and Professional Services Strategy[9], the Smart Cities Strategy[10] and the Information Economy Strategy[11] to provide a consistent vision of how a high performing, transparent economy that efficiently delivers services to all of its citizens can be created.

The aim of DBB is to provide a seamless transition from the achievements of Level 2 BIM and the Construction Strategy in to an environment where technology and working with technology is second nature in construction. This will fulfil the vision of digital enabled transformation of the full lifecycle of the built environment to increase productivity, improving economic and social outcomes. This will enable a thriving UK Digital Economy for the Built Environment, encouraging growth and competitiveness and facilitating dramatically better use of current and future built environment assets.

> *"Over the long term, increased productivity is the key determinant of economic growth, and together with higher employment is the primary route to higher living standards."*
>
> ***Dame Karen Dunnell, National Statistician and former Director of the Office for National Statistics***

The DBB programme will enable the government to achieve the following strategic objectives:

- **reduce the total expenditure associated with the built environment**: Information-enabled transformation will enable optimisation across the built environment lifecycle, resulting in reduced whole-life costs. For example, information that can enable changes in maintenance and energy use or enable advanced manufacturing techniques to drive down costs

- **maximise the return on investment in the built environment:** Enable trusted data-driven decision making through integrated strategic financial investment planning to promote transparency, cost certainty and provide confidence that every pound invested as part of the £300 billion NIDP[12] will be maximised

- **increase availability, capacity and performance of the existing built environment:** The majority of infrastructure planned to be available in 2050 is already in existence. This programme will define a commercial and information framework to accelerate the development and application of new disruptive technologies to increase performance and get the most value out of the existing built environment. For example, acceleration of connected and autonomous vehicles or built environment 3D printing

- **drive growth in the UK's information economy:** New technologies, skill sets and high-paid employment opportunities that drive growth and create valuable export opportunities. For example, through the formation of data scientists using advanced artificial intelligence algorithms, robotics systems, big data analytics

The DBB programme supports the policy objectives of:

- Department for Business, Energy, and Industrial Strategy
- Department for Digital Culture, Media and Sport
- Ministry of Housing, Communities & Local Government
- HM Treasury
- Department for Environment, Food & Rural Affairs
- Cabinet Office and Infrastructure Projects Authority
- Department for Transport
- Department for International Trade

An assessment of how the DBB programme fundamentally supports each of these policy objectives is provided in Appendix A.

2. Strategic Case

2.1. Introduction

The Strategic Case outlines the case for change and tests the applicability of information-enabled transformation and the overall link to improved productivity and economic growth.

The Strategic Case investigates the following:

- contribution of the built environment to economic growth
- built environment constraints on the UK's economic growth
- market failures
- DBB programme vision, approach and beneficiaries
- DBB programme outputs
- information as an enabler to drive greater economic growth from the built environment

The Strategic Case concludes there is a strong case for change. The previous work of DBB has proved the validity of the approach, whilst the SOBC work has confirmed its wider applicability and overall link to improved productivity in a way that directly enables the innovation, skills, infrastructure, procurement, energy and regional growth pillars of the Industrial Strategy.

2.2. Strategic Economic Relationship

2.2.1. Contribution of the built environment to economic growth

Increasing productivity and economic growth is directly dependent on the effectiveness of the built environment. The built environment connects people, goods, services and resources; which drive economic growth.

> *"Better buildings and infrastructure contribute to productivity not just through their primary function or by increasing economic growth. By making people happier, safer and healthier, benefits which are often overlooked, the built environment encourages them to be more productive".*
>
> ***Paul Nash, Senior Vice President, CIOB***[13]

The UK government is planning, developing and redefining the built environment in order to create thriving communities that improve quality of life for citizens and generate better returns for the economy. A highly developed and sustainable built environment is an important foundation upon which to build economic wealth. Considerable increases in economic growth can be achieved through efficiencies in all phases of the built environment economic lifecycle as shown in Figure 3.

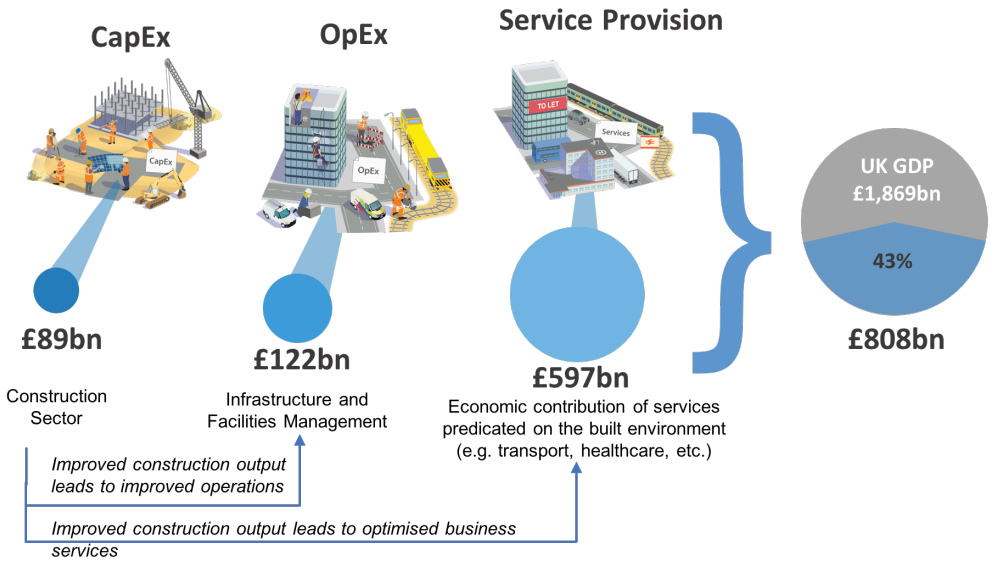


Figure 3 - The scale of value and economic activity associated with the built environment

In 2016, approximately £89 billion was spent annually on capital expenditure with the construction of new assets. This includes the planning of new schemes, the design phase where the architects and engineers detail the scheme, and the construction phase where the asset is built and handed over to operational use.

Once the asset is built and handed over it must be managed and maintained throughout its operational life. In 2016, approximately £122 billion was spent annually on infrastructure maintenance and facilities management activities associated with the existing assets in the built environment[14],[15],[16]. This includes hard services such as the periodic inspection, preventative condition and risk based maintenance of an asset, along with soft services such as cleaning, manned security, waste management and welfare.

Assets are built and maintained to provide the infrastructure that supplies a service to deliver outcomes of economic and social value. How well an asset performs will have a direct impact on the level, quality and consistency of the economic and social value created. The economic contribution predicated on the built environment, in 2016 was around £597 billion[17] (Service Provision). For example, a road provides transportation links for goods and people between locations of residence, enterprise, care or social interaction. If the road network does not have the capability or capacity to provide repeatable congestion free movement, this will impact on the UK economy.

In total the construction sector, infrastructure and facilities management, and service provision predicated on the built environment, contribute £808 billion to the UK GDP (43% of GDP) in 2016[18]. These figures reveal the extent to which increased economic growth can be achieved through optimising the existing asset base and the services predicated on those assets.

Additionally, economic growth can be increased by optimising the strategic financial investment planning of the built environment through better collaboration between different government departments, private sector and regulators, as illustrated in Figure 4. Currently, decision making and planning is occurring in silos, which is resulting in limited sharing of information and understanding of requirements, mismatched objectives and reduced return-on-investment. For example, transport networks should be strategically planned to connect people with employment opportunities and services, taking into account land that has been earmarked for housing and commercial development. Schools and hospitals should be planned with an understanding of existing and future needs of communities, taking into account population size, demographic changes and transport links.

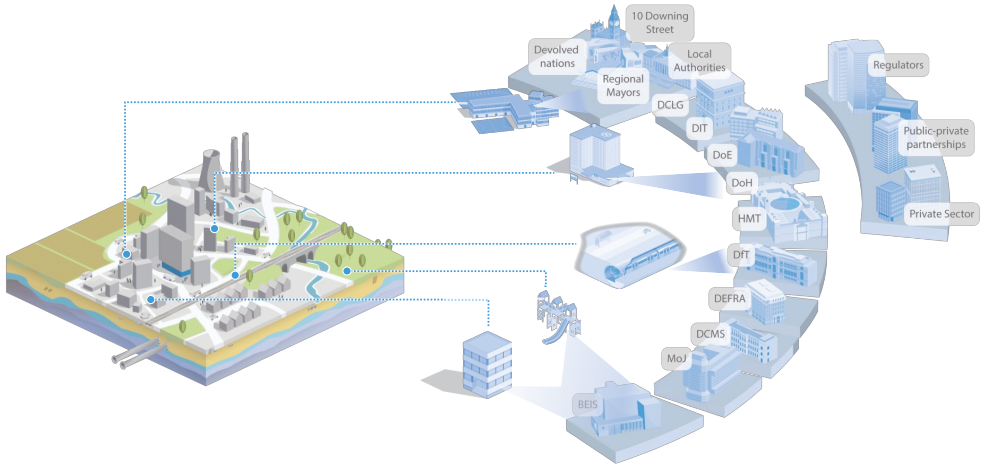


Figure 4 - Strategic financial investment planning takes place in information silos

2.2.2. Built environment constraints on the UK's economic growth

The built environment is a key enabler to productivity and economic growth, however, it is currently acting as a brake on economic growth. Traffic congestion cost the UK economy £31 billion in 2016[19] and the NHS spends £600 million per year[20] treating illnesses caused by living in poor housing conditions. The increase in the UK population and changing demographics (in particular an aging population), will place significant strain on the existing built environment and the services it provides, further limiting economic growth.

Further examples of constraints throughout the economic lifecycle (strategic financial investment planning, CapEx, OpEx and service provision) are provided in Figure 5. Additionally, detailed information on the impacts of some of these constraints is provided in Appendix B.

> *"A poor quality built environment and poor quality places can have significant negative impacts for health, wellbeing, prosperity and happiness"*[21]
>
> ***House of Lords Select Committee on National Policy for the Built Environment***

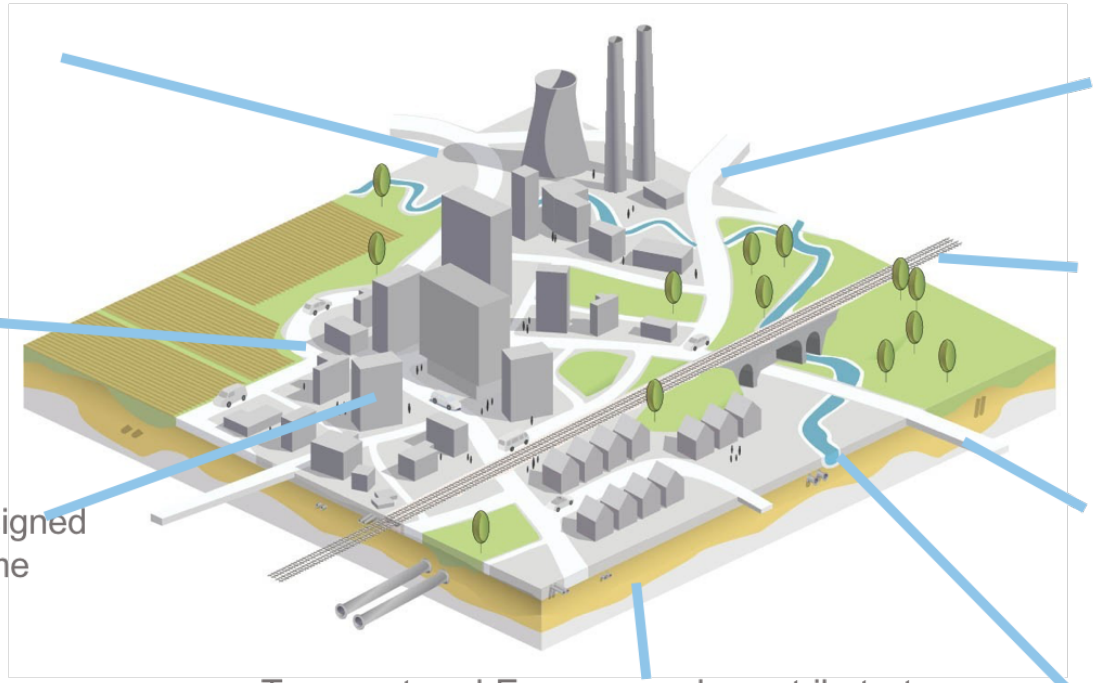


Figure 5 - Constraints in the UK's built environment is limiting economic growth

2.3. Market Failures

The UK does not optimise the value from existing and planned built and natural environment assets throughout their full lifecycle. Addressing this issue is essential to secure the greatest value from these assets if the economic growth and needs of citizens are to be met at an acceptable cost.

The increase of available data in the built environment provides an opportunity to optimise the use of assets and the consumption of services. However, there is no effective market for usage of built environment data to support asset optimisation. Current data management practices and information systems are not robust enough to back the growth in this market.

> *"The market does not necessarily drive change. DBB is so important that the state needs to intervene. This is the only way to drive behavioural change."*
>
> ***Neil Gibson, Executive Director, at Buckinghamshire County Council (Sponsor of the Cambridge – Milton Keynes – Oxford Corridor)***

The key market failures that hinder efficient information transactions and productivity improvements are of the following nature:

- **commercial:** a commercial framework to enable the optimisation of the delivery, management and operation of the built environment is lacking. Furthermore, the existing information and commercial frameworks hinder innovative approaches to investment in construction and optimisation of the built environment
- **cultural**: in a fragmented and output-led industry there is often a lack of trust or disregard for the available information either in the present linear process or taking into account feedback from downstream activities. This is compounded by an uncertainty over the nature of relationship, for example collaborative, cooperative or transactional, at the various stages of the asset lifecycle
- **security:** the existing information and commercial processes mean considerable commitment by the asset owner and its supply chain is required to ensure appropriate levels of trust and security are achieved and managed through the lifecycle of the built asset. The issues increase when the security and trust of a built environment is considered
- **technical:** the appropriate information framework is not in place, to support information integration and transactions through the full lifecycle of the built environment, and across multiple asset systems

Unless significant changes are introduced to information management practices, opportunities to capitalise on the developments in digital design, asset management and artificial intelligence, Smart Cities and the IoT will not be exploited.

2.4. DBB vision, approach and beneficiaries

To enable the DBB programme to achieve its vision, a framework has been designed, underpinned by both business and technology components required for the successful delivery of the programme. This framework is referred to as the System Engineering Framework. The approach to developing the System Engineering Framework is provided in Appendix C.

The System Engineering Framework is illustrated in Figure 6. It is a conceptual blueprint, visually articulating the 'case for change' and the ambitions of the DBB programme. The System Engineering Framework consists of the following segments. Each segment will be discussed further in the subsequent section:

- DBB programme vision
- strategic objectives
- beneficiaries
- outcomes
- information enabled capabilities
- commercial services
- information management ecosystem

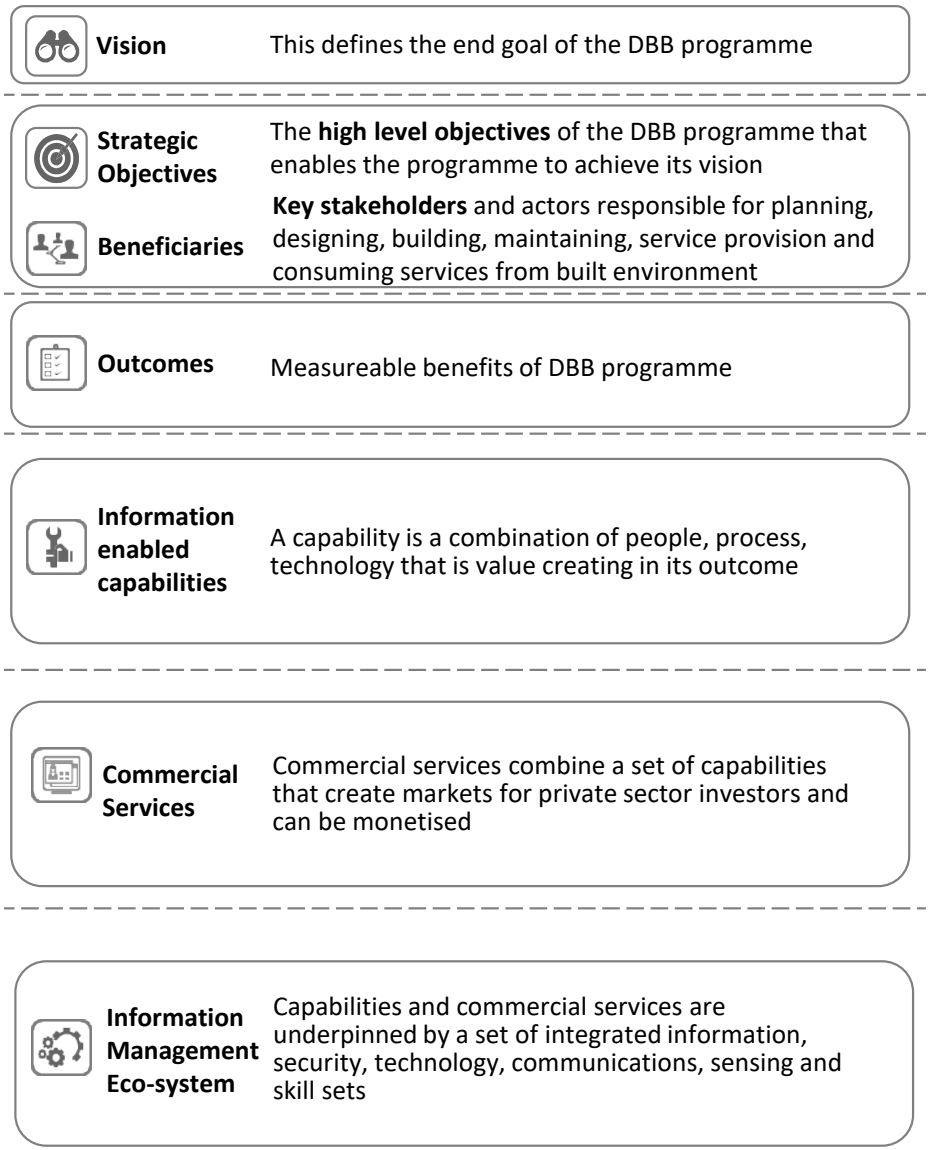


Figure 6 - System Engineering Framework

The System Engineering Framework will help to:

- visually map information enabled capabilities, commercial services, process and technology changes required
- generate a shared understanding of the terminology that is consistent, connected and coherent

The System Engineering Framework provides a means of moving the programme forward while retaining clear alignment between the overall policy objectives of government, sectors and beneficiaries.

2.4.1. DBB programme vision

Vision	This defines the end goal of the DBB programme

The vision of the DBB programme is the digital enabled transformation of the full lifecycle of the built environment to increase productivity, improving economic and social outcomes This is illustrated in **Figure** 7, which shows how information throughout the asset life cycle is used at increasing levels of maturity, (indicated by the levels) in an integrated manner across government and the private sector to increase UK productivity. This will achieve the following strategic objectives:

- reduce total expenditure
- increase capacity, availability and performance
- improve quality of life
- increase inward investment and increase ROI
- drive economic growth

Digital Built Britain Vision

Digital enabled transformation of the full lifecycle of the built environment to increase productivity, improving economic and social outcomes.

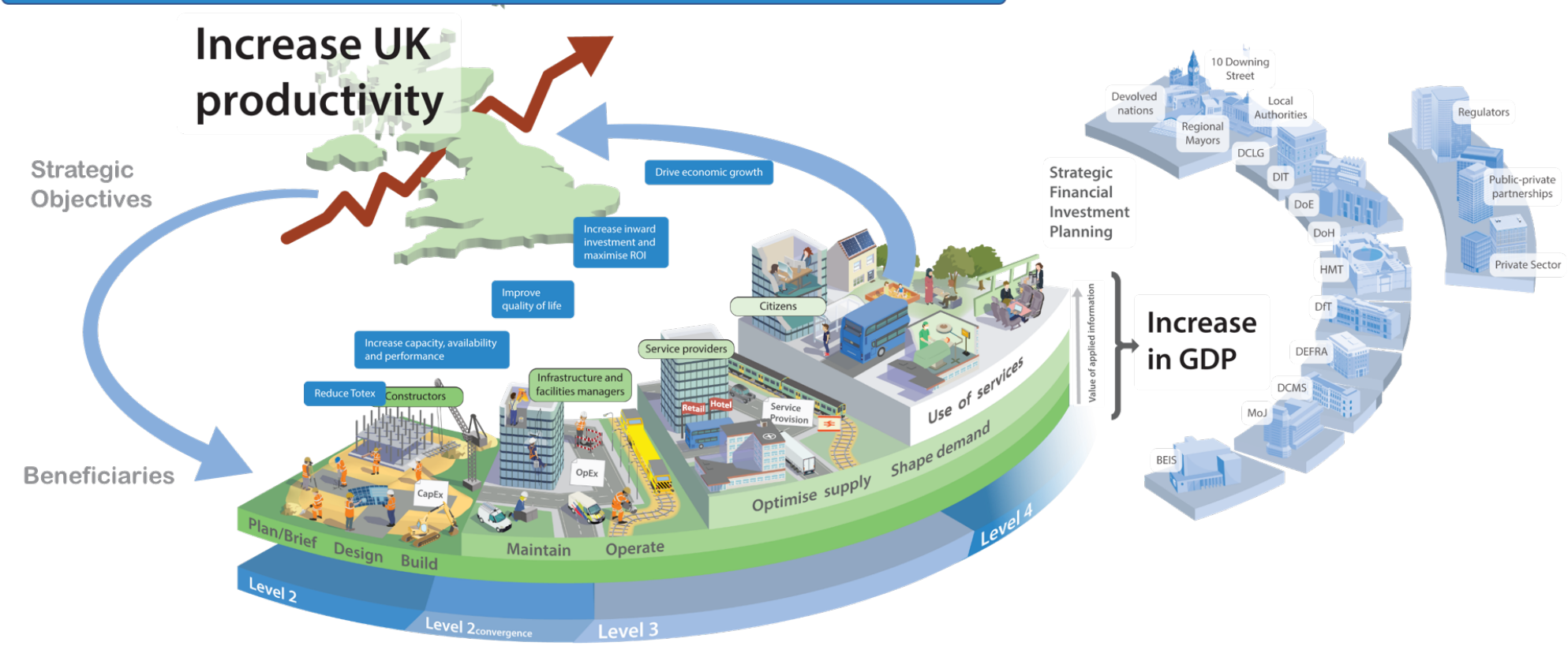
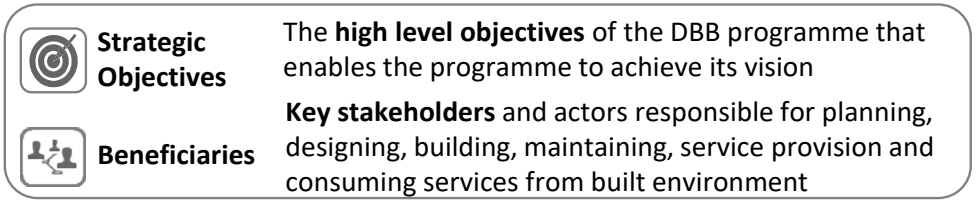


Figure 7 - DBB improves productivity across the full built environment economic lifecycle

2.4.2. Strategic objectives and beneficiaries



The strategic objectives of the DBB programme listed in section 2.4.1, are aligned to the beneficiary groups in Table 1. This is to illustrate how the DBB programme will have a positive impact throughout the economic value chain, improve societal outcomes and improve productivity.

Strategic Objective	Beneficiary Group
Reduce Total Expenditure (TotEx)	Constructors, infrastructure and facilities managers, asset owners
Increase capacity, availability and performance	Service providers and businesses, asset owners and recipients of the service
Improve quality of life	Citizens
Increase inward investment and maximise return on investment	Public and private sector
Drive economic growth	Government

Table 1 - Strategic objectives alignment with each beneficiary group

The primary beneficiaries are then mapped to the built environment asset life cycle in Table 2. This shows how DBB programme will benefit all stages of the lifecycle in the fulfilment of the strategic objectives.

Built Environment Economic Lifecycle	Beneficiary Groups
Plan, Design and Build	Government, construction sector clients and project finance (CapEx)
Maintain and Operate	Infrastructure maintenance and facilities management sector (OpEx)
Optimise (Optimise Service Provision)	Service providers delivering services heavily dependent upon built environment infrastructure
Optimise (Use of Services)	Citizens and business using services
Strategic Financial Investment Planning	Government – Local and National, Public Private Finance initiatives and private sector

Table 2 - Built environment economic lifecycle and beneficiary groups

This provides a basis for a future understanding of how benefits profiles can be developed, how realisation can be managed and measured, and what the role of each beneficiary group may be in ensuring the sustainability of the future DBB solution.

2.4.3. Outcomes

Outcomes	Measureable benefits of DBB programme

The DBB programme will provide beneficial outcomes throughout the life cycle of the built environment improving productivity and society and aligned to the policy objectives described in Appendix A, through:

- doing more with the same
- operating for less
- optimising service provision
- improving quality of life
- growing the UK economy

This is summarised in Figure 8 and expanded in the subsequent section.

Figure 8 - Outcomes of the DBB programme.

Doing more with the same

Approximately £90 billion is invested annually in the construction of new assets. Significant improvements must be made in the construction industry in order to address its productivity challenge. For example, the UK is currently building less than half the number of homes to meet population growth and tackle the backlog in housing caused by decades of undersupply, with 1.7 million families on waiting lists for affordable housing[22].

Inefficiencies in construction are widely recognised in the industry. The construction sector projects are often considered bespoke and therefore current practices remain unchanged. The risk-adverse nature of the sector, driven by the impact of failure caused by low margins, compounds this challenge. The productivity and predictability benefits that have been seen in other sectors have yet to be realised and assets often fail to meet expectations in quality, delivery time, build and cost, and have a large performance gap from design. These failings are accepted as business as usual and contingencies and risk provision do not have the desired effect, often increasing the time to operational benefit being realised.

Current contractual frameworks, commercial processes, and fragmentation in the construction sector are barriers for the adoption of best practice from other industries, such as the adoption of manufacturing approaches to drive efficiency. Where manufacturing approaches have been adopted, these have largely replicated traditional construction methods in a factory setting.

Furthermore, an adversarial and non-collaborative culture in the construction industry creates barriers to entry for SMEs and providers of innovative technologies and solutions.

DBB will address this by:

Improving construction productivity: shorter build times and the reduction in construction schedules, timelines, rework and change orders. For example, off-site manufacturing of standard components to help address the housing deficit and efficiently build communities.

Conducive commercial environment: creating a transparent commercial environment with trusted information at the core. This will remove the adversarial

exchanges associated with ambiguity, as decisions will be made based on authoritative information.

Accurate and predictable cost models: Timely completion of projects, reduced over-procurement and change orders. For example, factory-controlled conditions and machine production increases control of environment and enables health and safety and quality improvements as well as the reduction in material waste and CO_2.

Operating for less

In the UK, approximately £120 billion is spent per annum on infrastructure and facilities management activities associated with the existing assets in the built environment. This cost represents 80% of lifetime cost of an asset of which 50% is spent on energy consumption.

Given that buildings account for 40% of the world's total carbon footprint, greater efficiency in operations can support a more sustainable built environment and reduction in energy consumption. In many cases, infrastructure is consuming up to four times more than its designed energy usage.

Additionally, there is huge cost and risk associated with time-based, or scheduled, maintenance activities. The inability to perform predictive maintenance can result in a 25-35% increase in maintenance costs.

DBB will provide a mechanism for:

Reduced operational expenditure: with availability of asset condition data, it is possible not only to understand impact on operational costs but forecast capital project cost as well. This is not limited to one asset (e.g. building) but scalable to multiple asset systems, cities, regions, etc.

Improved asset performance: consistent and standard view of asset system utilisation, carbon impact and performance across multiple geographies allows efficient energy consumption and increase availability.

Improved operational efficiencies: risk or predictive maintenance of asset systems reducing the operational risks associated with the asset systems, for example unplanned maintenance due to signal failure. This enables better resilience of asset to deliver services and minimise disruption to services delivered to citizens.

Secure and low cost transactions: reduced latent transactional costs due to reduced fragmentation and digitalised supply chains, whilst ensuring an increase in security.

Optimising service provision

The UK's infrastructure is already stretched. In 2014, 26% of morning peak trains arriving to London were over-capacity. The UK population is forecasted to increase by 9.7 million (15%) over the next 25 years, which will put additional strain on stretched infrastructure. The UK is currently building less than half the number of homes to meet population growth and tackle the backlog in housing caused by decades of undersupply, with 1.7 million families on waiting lists for affordable housing. Approximately 80% of the dwellings that will exist in 2050 have already been built.

Most service providers find it difficult to deliver effective performance improvement programmes, in large part due to barriers associated with availability of data, willingness to collaborate and ability to invest in change programmes.

DBB will provide the mechanisms to address this through:

Improved asset utilisation: by enabling the provision of information of the right quality, and in the context of the appropriate commercial frameworks, the Digital Built Britain programme can enable service providers to optimise the capacity of their asset base by shaping demand and supply.

Optimised profitability: Digital Built Britain enables organisations to capture performance and operational cost data, supporting improved cost management. Further, enabling an extensible information landscape provides the foundation for a TotEx cost management breakdown structure.

Improved service delivery: Digital Built Britain enables the optimal use of assets to deliver citizens fast, high quality services within a desirable timeframe that support social, fiscal and growth ambitions.

Reduced service disruption: visibility of supply and demand coupled with connected supply chains and logistics enable dynamic scheduling and capacity planning when responding to disruptions.

Reduced wastage: responding to demand in an accurate and timely manner will reduce the waste of over-capacity.

Improved quality of life

The built environment, in combination with our physical and mental health, impacts our quality of life. Furthermore, the interventions to improve lifestyle or health are likely to be influenced by the environmental and socioeconomic context in which they take place. This includes several material determinants of health, including housing, neighbourhood conditions and transport routes, all of which shape the social, economic and environmental conditions on which good health is dependent. Within urban areas, the imaginative integration of built and natural features can help to create environments that are unique and interesting enough for people to lead varied and healthy lives. Currently responsibility for all of these factors is shared across local and national government, with no agency having either the information or overview of the interdependent factors and outcomes.

This will be addressed by DBB facilitating:

Improved well-being: when the factors and indicators of wellbeing can be measured, it is possible make and monitor decisions and interventions based on causal factors.

Improved value for money: due to the complexity and independency of factors that contribute to quality of life, many interventions are made with good intention but in the absence of information. This can lead to inefficiencies for society and the public purse.

Improved personal productivity: if we can spend more time doing the things that we enjoy and create value, our personal productivity will improve along with that of the nation.

Improved convenience: creating the mechanism of having the information readily available to make an informed decision for the individual or the service provider will simplify many value chains.

Improved engagement and satisfaction: if there is visibility about the quality of service provision and the socioeconomic impact, individuals are more likely to be engaged with society. The transparency of the information can be used to improve service provision and satisfaction.

Grow economy

Britain suffers from overcrowded and congested transport links, insufficient housing, overburdened healthcare services, a shortage of schools and inadequate localised energy supply. Furthermore, a rise in the proportion of the elderly in our population and a growing total population, will result in increasing fiscal pressure and place greater demands on our social and economic infrastructure. Significant improvements need to be made in the planning of the built environment to meet the needs of the UK growth if this is to be done without significantly increasing national debt.

Growing the economy and addressing the UK productivity challenge is a key aim of the UK government. However, over the past decade, the UK's GDP growth has been consistently lower than the world average. The ability to plan investment strategically to best use the limited budget for the built environment is essential to grow the UK economy.

DBB will address this through:

Accelerating economic growth: creation of industrial and digital hubs enhancing the value of the UK asset base, and enable the up-skilling of the workforce through the creation of new skilled, digital market opportunities.

Creating new markets, businesses and services: strategically placed jobs and infrastructure enables the creation of new services, from increased breadth of available data, with the skills to deliver these services.

Improving global competitiveness: creation of digital hubs and availability of the UK's digital and physical infrastructure to increase competitiveness.

Growing UK information economy: information will drive the UK economy. The UK aims to be a global leader in the information economy. This position will be underpinned with the expansion of this high value sector

Reducing environmental impact: ability to plan across the built environment to protect and reduce impact on the natural environment.

Safe and secure infrastructure: better investment decisions made based on citizen needs, location, local growth actions, transport and utility requirements from a planned and unplanned perspective.

2.4.4. Information-enabled capabilities

Information enabled capabilities

A capability is a combination of people, process, technology that is value creating in its outcome

Through introducing information standards and a trusted high quality integration framework for built environment infrastructure, DBB enables the development of new information-enabled capabilities required to realise value and achieve the programme outcomes. A capability is a combination of people, process and technology, enabled by information that is value-creating in its outcome. Figure 9 illustrates examples of capabilities required to enable the identified benefits across the different beneficiary groups.

These include:

Innovative planning, design, manufacturing and construction approaches: informed by a combination of standard module options and feedback on the asset performance of similar schemes. New schemes can be developed using the rule-sets of function, cost and sequence created using artificial intelligence, captured using parametric design methodology and produced using a combination of off-site manufacturing and on-site production.

Performance and risk based real-time infrastructure systems management: the surfacing of discreet information about an asset's condition, whether it be the number of users of a space, the duty cycle on a motor or the wear of a road surface, and comparing against performance profiles will enable maintenance intervention when needed. Relating this information to the business operational or service provision impact will inform which assets are business critical. This will reduce the cost of maintenance and improve the operational performance through intervention when needed and to mitigate any risk on the business performance.

Optimisation of supply to demand in near real-time: in today's complex multiple input and output vector world, it is very difficult to use static models based on traditional patterns of behaviour to balance supply with demand. If the demand and supply are known in real-time at a granular level, it is possible to refine the models using machine learning and artificial intelligence to ensure there is appropriate balance without expensive overcapacity. When adjacent systems are also included in the models, the prediction of demand and supply can be further optimised with distributed intelligence and decision making. For example, optimising the capacity of a road network by having a network model that integrates the vehicle satnav request into speed control, ramp metering and routing.

Enhancement of service offering: having a better understanding of a portfolio of assets and their performance within an ecosystem of systems, and the service quality achieved will provide the service operators with valuable insight. This visibility will enable service offerings to be optimised, which can lead to improved outcomes such as reduced cost or increased customer satisfaction. For example, if the demand for a service was consistently high, with an appropriate lead-time, it would be possible to create more capacity if the economic case supported the investment. Alternatively, behaviours can be nudged to smooth any peak loading within a system. This approach applies across different service provisions from energy to health care to transportation.

Strategic investment planning across infrastructure systems and geographies: creating new infrastructure is not trivial. It is expensive, takes a long time to complete and has uncertainty about installed capacity. Using traditional isolated linear models of behaviour, the interaction of other systems is not considered, nor the impact from enabling technologies and the impact on the future skills base. For example, when developing a new regional plan, having the information readily available with clarity and granularity of the integrated energy model and transportation network model. This will enable the scheme under development to identify the capacity and capability within the energy and transport systems to ensure the outcomes anticipated are not constrained but enabled by the built environment.

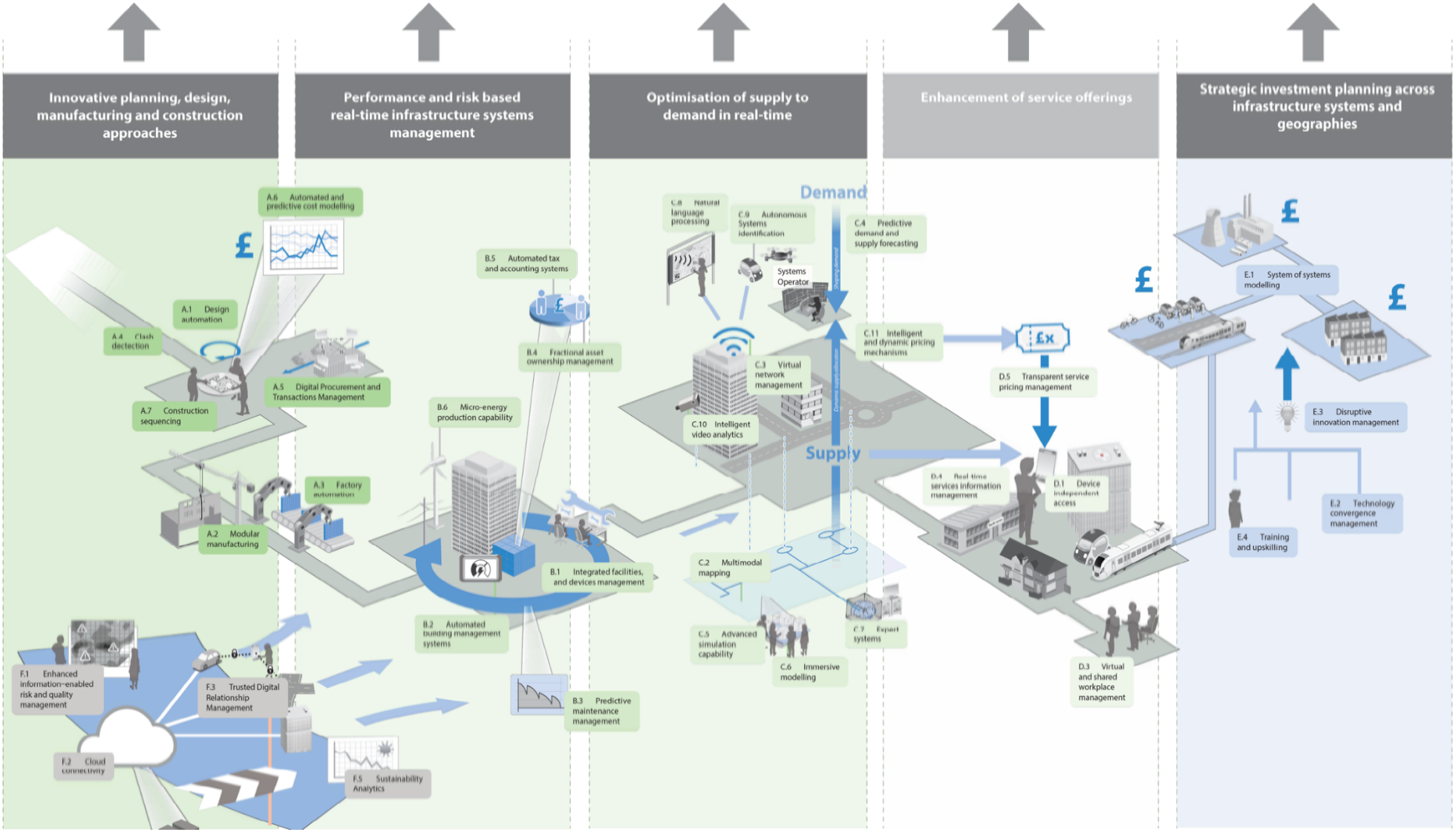


Figure 9 - Information enabled capabilities of the DBB programme

2.4.5. Commercial service

Commercial Services

Commercial services combine a set of capabilities that create markets for private sector investors and can be monetised

Commercial services combine multiple capabilities to deliver services that can potentially be monetised. They represent 'industrialisation at scale', with both domestic and global reach. For example, intelligent demand response management requires a systems operator that has a predictive demand and supply forecasting capability. This capability does exist today in a few isolated silo applications. The standards introduced by DBB would create a much broader, scalable market for a business services provider wishing to specialise in this space.

Further examples of commercial services that could be driven at scale through the work of DBB are illustrated in Figure 10, providing the principal mechanism by which private sector funding can be leveraged by the programme.

These include:

Module catalogue of standard components: if information about the built environment were to be made available in an integration framework, this could enable a catalogue of standard components to be developed. These modules could form the basis for many schemes with specific adaptation as needed. They would be optimised by user feedback to improve their application, cost or quality. This would encourage competitive tension in the market as the volumes would support capital investment in machinery and process optimisation.

System performance benchmarks: benchmarking performance is a well-established approach. The process of gathering accurate and trusted information needed to establish a benchmark can be a barrier to use. DBB seeks to provide a framework in which trusted and accurate information can be captured at scale. This will enable performance benchmarking on a scale never seen before giving insight of intervention options that could be made at a city, region or nationally. For example, if this approach was used for understanding building energy consumption, the number of buildings and the details about their composition and use would be available.

Big data and analytics: the data which could be shared as part of the DBB programme would be of interest to the data analytic and artificial intelligence community. This will be the first time such a large trusted data set across diverse systems and systems-of-systems within the built environment will be made available. Patterns emerging from such an activity would help us understand our built and natural environment with more clarity, creating opportunities for commercially viable improvements and innovation and thereby delivering new commercial services.

Digital contracts: the basic form and administration of contracts in the built environment has not changed significantly over the years. They set out the obligations of each party, a route to remedy in the event of non-performance and the assurances needed. If the information about the asset was central to the contract and was populated as the asset matured throughout the lifecycle, the often adversarial relationship would be removed.

Intelligent demand response: if the capability and capacity of a delivered service for a city or region were defined and understood in near real-time. It would be possible to model the demand response ahead of action to mitigate for unintended consequences and ensure anticipated outcomes. Once the intervention is made, the actual condition through the systems could be monitored and optimised. This approach would be applicable across a variety of systems including city services, transportation, energy and healthcare.

Demand side brokerage: the UK electricity grid has National Grid as a system operator. They have a challenging task of managing supply and demand without having sight of all the information about supply from micro-generation or demand at a granular level. DBB could enable the information to be made available in a framework that would allow demand brokerage and balancing at a level lower than National Grid currently are able. This allows new services to be introduced where the demand and supply can be locally balanced through the measures available within that community such as storage, load shedding and renewable feed-in.

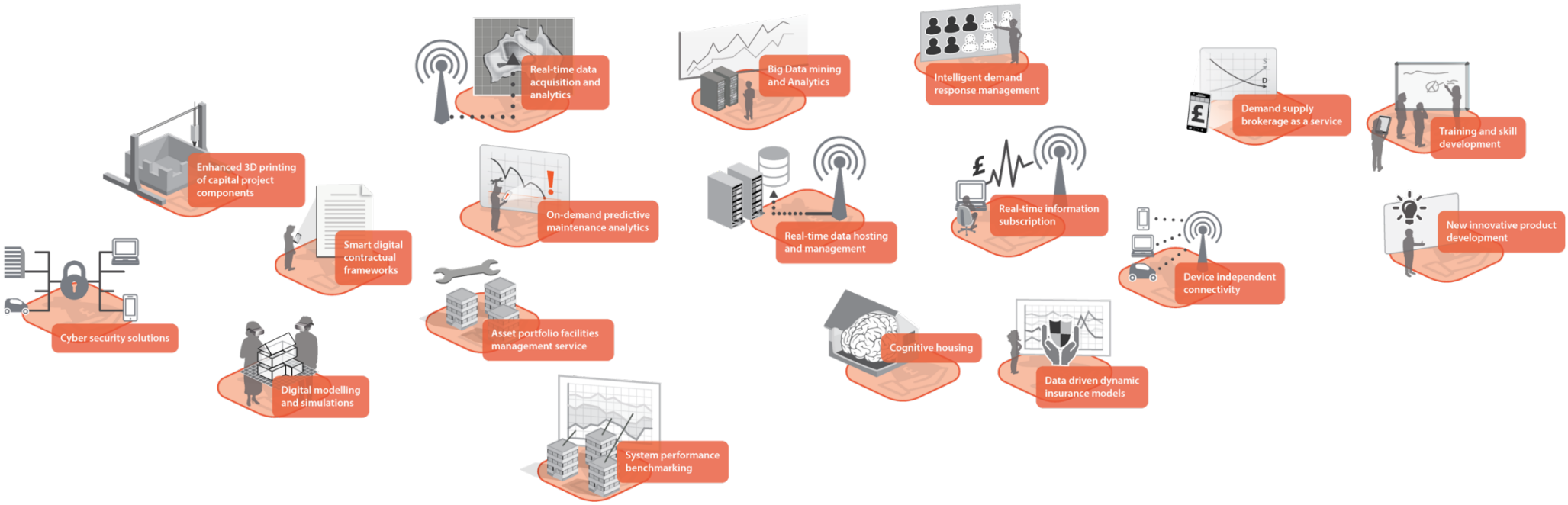


Figure 10 - Candidate commercial services of the DBB programme

2.4.6. Information management eco-system

Information Management Eco-system

Capabilities and commercial services are underpinned by a set of integrated information, security, technology, communications, sensing and skill sets

The System Engineering Framework is underpinned by an information ecosystem, as illustrated in Figure 11. While further work to develop the ecosystem solution will be carried out as part of the next steps of the programme, it is envisaged that this ecosystem will consist of the following components:

- **data collection:** data sets captured from natural assets, built assets, users and mobile assets are required to inform the information-enabled capabilities and commercial services (e.g. asset capability, utilisation, demand, capacity, demographic, weather, and geological)
- **communications layer**: the communication layer enables high volumes of data to be transmitted to relevant data centres (e.g. high speed telecoms networks)
- **integration layer:** joining and connecting relevant information in a common language, the rich information collected from the built environment is collated to provide an integrated view of asset systems across communities, cities and regions. This will enable optimisation across the built environment lifecycle, allowing integrated strategic financial investment between multiple stakeholders
- **data-to-intelligence:** the business process layer consists of technology solutions required to generate insightful knowledge to drive data-driven decision-making processes (e.g. solutions for storage of data, high performance computing, machine learning and artificial intelligence)
- **skillsets:** the availability of new information and capabilities will result in the need for new information intelligence skillsets to make efficient use of this information

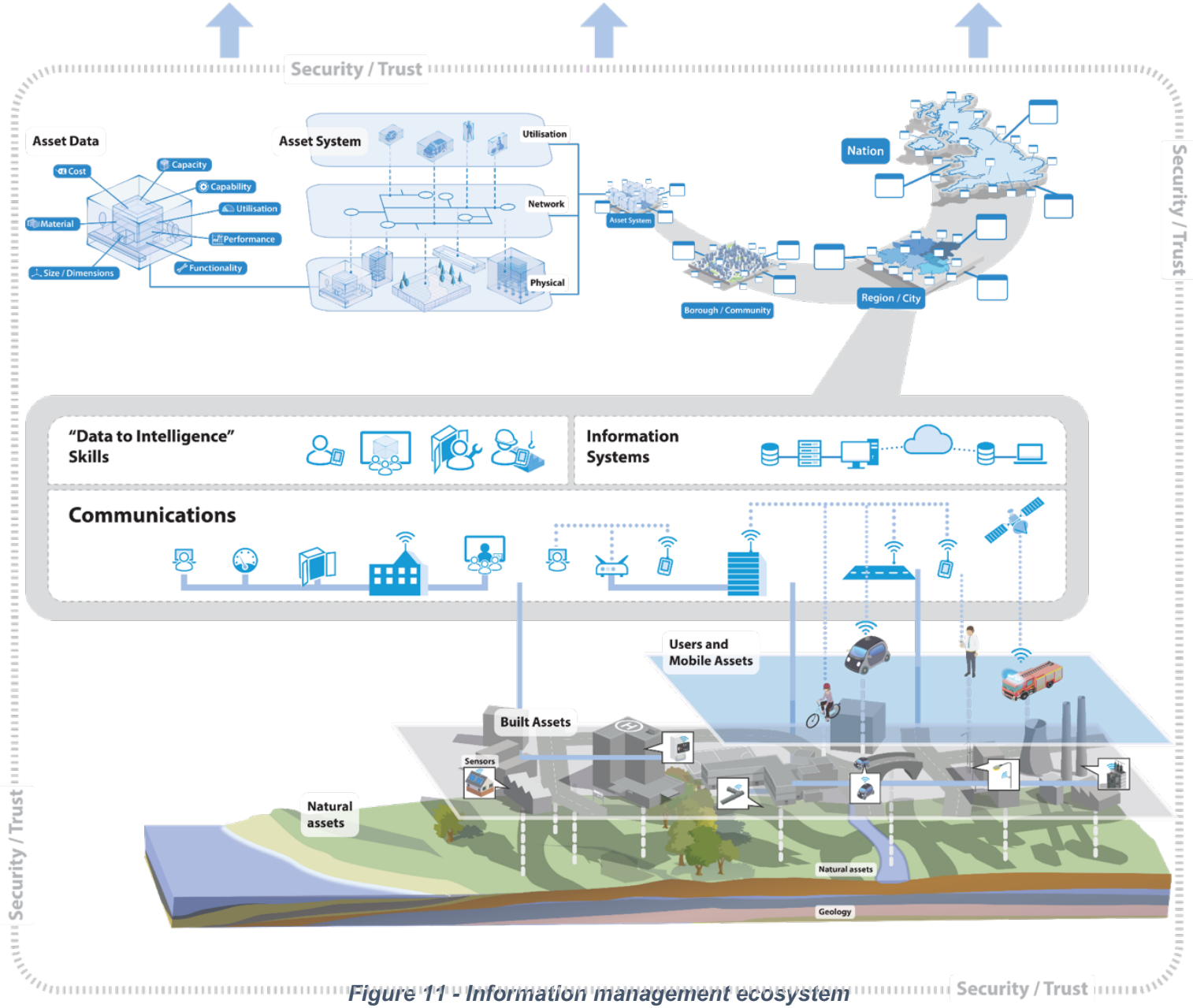


Figure 11 - Information management ecosystem

2.5. Benefits of this approach

DBB seeks to enable the realisation of economic gains throughout the full built environment economic lifecycle. The scale of the opportunity is set out and shown for each of the elements of the built environment economic lifecycle.

This section describes how DBB drives efficiencies across CapEx, OpEx, service provision and strategic financial investment planning. Each section will show a case study of how these have been explored in each area.

DBB would enable developers, architects, engineers and constructors to do more for the same cost

There are opportunities to unlock further efficiencies throughout the construction sector, which can be addressed through improved asset information, as illustrated in Figure 12.

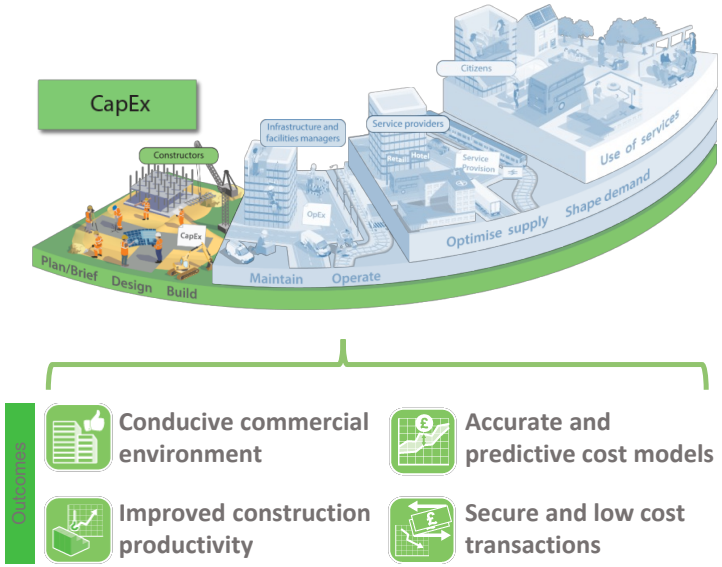


Figure 12 - DBB programme CapEx outcomes

DBB would achieve this by:

- increasing surety of outcomes
- reducing waste throughout the process
- digital brief based on live feedback of asset operation into construction
- enabling the adoption of manufacturing approaches in construction
- increasing access and availability to trusted, interoperable and machine-readable data
- promoting autonomous processes for construction
- enabling new forms of procurement

Case study: Anglian Water using manufacturing approaches [23]

What was the challenge and the need for change?

Being one of the largest energy users in the East of England, Anglian Water is under pressure to reduce energy costs and greenhouse gas emissions.

How was this solved and what benefits were unlocked?

Anglian Water developed an approach whereby assets are considered 'products, not projects'. It designs, manufactures and tests its assets off-site. They have developed a digital asset catalogue that contains all assets used in water centres, containing information on the use of each asset, operation details, components and associated 3D models. Additionally, it includes information on how assets should be integrated into the wider network.

When planning and designing a new centre, assets can be selected from the catalogue according to site specifications. This approach was applied to sampling kiosks – a facility from which samples are taken from reservoirs for pollutant testing – that are now produced offsite. By applying limited manufacturing approaches and combining data sets such as mapping data and environment agency data they have delivered 23% cost savings, 11% carbon savings and a 50% reduction in installation time.

Lessons learned

The approach chosen by Anglian Water has enabled repeatability, driving greater efficiency in production, installation and project delivery by bringing different data sets together.

What could DBB do?

The market is currently failing to scale the manufacturing approaches used by Anglian Water across the wider water industry (or other industries) and across the country. DBB, through creating a national framework of information sharing, and introducing the appropriate incentives can drive the adoption of manufacturing approaches across sectors and geographical locations.

DBB enables infrastructure and facilities managers to operate for less

Future benefits could address the operational cost of an asset as shown in Figure 13. This is up to 80% of the lifetime asset cost, of which half is spent on energy consumption.

Figure 13 *- DBB programme OpEx outcomes*

DBB would achieve this by:

- optimising CapEx and OpEx balance
- reducing waste throughout the asset lifecycle
- improving operational availability
- sharing trusted real-time integrated data from individual assets to asset portfolios
- driving active monitoring, management and operation of infrastructure leveraging strategic insights from real-time integrated data
- safely extending infrastructure asset life resulting in fewer whole-asset renewals

Case study: Network Rail, ORBIS programme[24]

What was the challenge and the need for change?

The Offering Rail Better Information Services (ORBIS) programme was implemented due to Network Rail's regulatory pressures and budget constraints. The programme established the information, tools and skills to enable Network Rail to become a more effective infrastructure asset manager.

How was this solved and what benefits were unlocked?

The programme implemented new business processes and decision-making tools to bring about significant and sustainable improvements in safety and asset performance across the UK rail network whilst delivering financial efficiencies. The programme delivered a 10% reduction in the overall maintenance budget, totalling £100 million per year, whilst improving asset reliability.

To achieve this the programme introduced new processes and systems to collect, evaluate, collate, analyse and apply information, turning that data into insight across Network Rail's £46 billon asset base.

Lessons learned

Much of the knowledge from the implementation could be transferred to other linear infrastructure sectors (such as highways, power grids, utility networks), the information architecture and tools are not, due to lack of standardisation. As part of the DBB programme new UK and/or international standards will be developed.

What could DBB do?

Build on the learnings of the ORBIS programme to provide accurate and interoperable data about location, condition, utilisation and performance for different asset systems.

DBB helps to optimise service output in near real-time

As our population continues to grow we can balance the demand with service supply. For example, in 2014, 26% of morning peak trains arriving to London were over capacity[25]. This is shown in Figure 14.

Figure 14 - DBB programme service provision outcomes

DBB would achieve this by:

- providing trusted information of the right quality supporting service providers to optimise the capacity of their asset base, shape demand and optimise supply
- enabling service providers to run analytics to forecast demand and supply in near real-time
- developing new services to manage the capacity challenges within the current capability a single or portfolio of assets

Case study: TfL releasing open data network updates[26]

What was the challenge and the need for change?

Transport for London (TfL) faced peak capacity issues and dissatisfaction during service disruption as customers, not informed about congestion or disruption were not aware of alternative travel routes during these periods. TfL started releasing open data network updates.

How was this solved and what benefits were unlocked?

TfL started releasing open data network updates. By making live network updates publicly available, TfL generated time savings due to avoidance of disruption of up to £58 million in 2012.

Furthermore, by releasing their data freely, app development in the market was incentivised. Existing and new businesses were allowed to develop new products and services based on TfL data. These apps that served TfL's customer base, and responded to transport users' growing demand to access data about TfL transport services via smartphones.

Lessons learned

While TfL was initially cautious when the decision was made to switch to open data, the risk paid off. TfL is now converted to open data and has been able to demonstrate the benefits of an open data policy to other stakeholders in the field.

What could DBB do?

By implementing a cooperative cultural environment that seeks to learn and share across government and the private sector, DBB will allow greater data sharing unlocking not yet considered benefits as well as creating new economic opportunities.

DBB helps integrated strategic financial investment planning

By integrating the demand across sectors, assets systems and geographies, DBB enables government to plan strategic financial investment more efficiently and effectively. This maximises the return on every pound invested as illustrated in Figure 15.

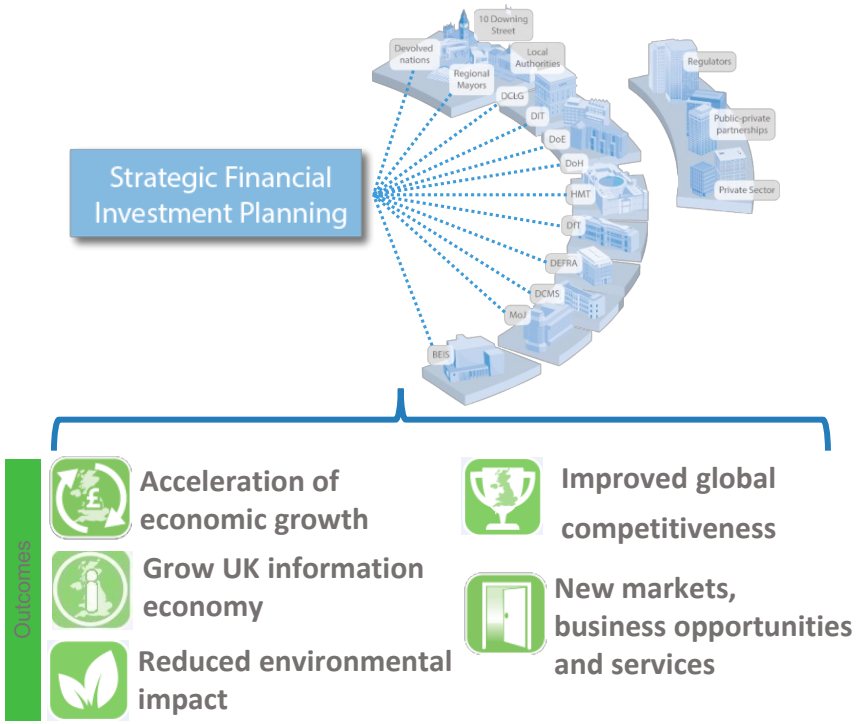


Figure 15 – DBB programme strategic financial investment planning outcomes

DBB would achieve this by:

- developing an information framework to enable shared access to trusted, interoperable, extensible and unambiguous information
- integrating information across sectors, asset systems and geographies
- creating an evidence-based information framework to support value based Green Book investment cases
- scenario modelling to aid understanding and effective decision making

Case study: Cambridge - Milton Keynes - Oxford Corridor[27]

What was the challenge and the need for change?

The Cambridge East-West Corridor programme sets out large scale, transformative developments that create new homes, road and rail infrastructure across the region to address the predicted housing, transport and employment demand forecast or 2035. This ambitious programme faces significant challenges. For example, there are 27 governance processes required for every collaborative decision, and a lack of quality and trusted data prohibits effective information exchange and modelling.

How was this solved and what benefits were unlocked?

The future productivity implication of sub-optimal investment planning could be considerable. The programme mitigates an anticipated increase on the primary east-west road route by 32-40%, which would drive levels of congestion that the Department for Transport has estimated would cost businesses in the region of £300 million annually.

Lessons learned

In order to accelerate the unlocking of the expected benefits from the Cambridge – Milton Keynes – Oxford corridor, a new way to facilitate collaboration and commitment at all stakeholder levels will be necessary.

What could DBB do?

The DBB programme will, through the introduction of a consistent shared data framework for the collection, collation, analysis and evaluation of data, ensure that integrated strategic financial investment planning can take place ensuring every pound that is invested is maximised.

3. Economic Case

3.1. Introduction

The Economic Case sets out 5 options for the delivery of the DBB programme vision. A high-level financial and non-financial appraisal approach was undertaken to provide the DBB board with a preferred way forward with a shortlist of potential options to be further analysed in the subsequent stage.

The SOBC Economic Case investigates the following:

- overview of options for delivery of the programme
- options financial and non-financial appraisal

The main purpose of the Economic Case is to demonstrate that the investment is worthwhile for the envisaged economic return. The DBB programme will enable an integrated view of built environment information across multiple asset systems. This provides an opportunity to make changes in government-funded capital spend that benefits the long-run operating costs of an asset and improves operations on existing assets that deliver service outcomes.

This opportunity is amplified when modelled across multiple services such as housing and transport, and leads to an accumulation of quantified and improved social value. The Green Book approach provides increasing levels of certainty in cost and return at each stage of qualifying the options for taking the programme forward.

3.2. Overview of options

In accordance with the Green Book approach, 5 options have been identified to deliver the DBB Programme. These were derived by a combination of:

- reviewing the existing strategy, policy and standards
- benchmarking analysis to determine the current market knowledge
- investigating state-of-the-art
- dialogue with leading industrial practitioners and academics

This resulted in a list of options. This list was assessed in combination with the DBB Client Design Authority (CDA) to evaluate whether the identified problems statements would be addressed with each solution. This was then subjected to an initial benefits analysis to determine whether the quantum was significant. Thereafter, a first evaluation of the implementation cost and timing was made. Throughout this process continued market engagement occurred to ensure insight was included and applicable options were considered.

This yielded a list of options shown in

Table **3** and expanded in Appendix H:

Option	Description
1	**Do nothing**: continue to support Level 2 'as-is'.
2	**Level 2 convergence**: leverage investment made in BIM, IoT and Smart City standards to create an interim solution to bridge the transition from L2 to L3.
3	**Integration environment focused around the buildings and strategic networks:** Information Management Landscape (IML) foundation ontology and Reference Data Library (RDL) for whole asset lifecycle informed by ISO Road Map and building on IFCs. RDL partially populated through Proof of Concept (PoC)/Pilots.
4	**Integration environment focused around built environment and functional city services**: IML foundation of Option 3 with RDL extended to asset-based functional city services, such as planning, transport, recycling and city based services for healthcare using technologies and approaches such as ISO15926 (iRing). Partially populated for through Proof of Concept (PoC)/Pilots.
5	**Integration environment and platform focused around built environment, city and consumer services**: IML foundation and content of Option 4 with RDL extended to optimisation of city services and provide consumer services such as education, police, fire and public safety, social care, libraries, trading standards. RDL data collected, validated and populated for government-owned assets with immutability and non-reputability using technologies such as distributed ledger. SW platform ecosystem developed and managed.

Table 3 - Option descriptions for DBB programme

This is detailed further in Table 4, setting out the sector engagement, adoption and anticipated timescales.

Option	Description	Sector Engagement	Adoption
1	Do nothing: continue to support Level 2 'as-is'	Existing Level 2 BIM industry bodies	Construction sector
2	Level 2 Convergence:	Qualify / pilot 2 primary high value application by sector or geography	Support adoption of recommendations in 2 high value applications
3	Integration environment focused around the Buildings and Strategic Networks	Qualify / pilot 2 primary high value application by sector or geography	Support adoption in 2 high value applications
4	Integration environment focused built environment & functional city services	Qualify and pilot multiple high value applications by sector or geography	Support adoption in multiple government departments. Incentivise adoption in industry
5	Integration environment and platform focused on built environment, city & consumer services	Qualify and pilot multiple high value applications by sector or geography	Support adoption in multiple government departments. Incentivise adoption in industry Industry develops platform and associated ecosystem

Table 4 - Option sector engagement, adoption and timescales

3.3. Options appraisal

3.3.1. Options appraisal framework

This section provides a framework that assists with the selection of the recommended options or preferred way forward. The framework is referred to as the options appraisal framework. The options appraisal framework has identified key financial and non-financial appraisal criteria for the long-list of 5 options.

Below are the financial and non-financial criteria identified by the options appraisal framework, to evaluate the 5 options:

- **non-financial appraisal** of options using following 3 criteria:
    - data framework: the data framework summarises the level of data taxonomy, accuracy, timeliness, completeness, ownership and ontology
    - information transactions: summarises the information transaction using data integrity, security, speed of transaction, volume, inter-operability and functional requirements
    - scalability and extensibility across high value sectors (HVS) and geographies: summarises the scalability (ability to accommodate growth) and extensibility (ability to add more functionalities) of the data framework and information transaction across HVS and geographies
- **initial financial assessment** of options
    - value for money: assessment on ability to optimise value for money, defined through analysis of projected costs vs. benefits

The high value sectors (HVS) were selected based on economic analysis of the government sectoral spend[28]. These HVS were determined to be Energy, Transport, Social Infrastructure, Water & Waste and Housing.

3.3.2. Non-financial appraisal

Appraisal methodology using the data framework

The realisation of DBB programme target benefits and outcomes is dependent on the effectiveness of the data framework. The data framework will allow creation of an environment where data has the following requirements:

- **standard taxonomy:** data must be defined and linked using logical hierarchy suitable for sharing and use within any system
- **accuracy:** data captured must be in the valid range and must be represented in a consistent and unambiguous form
- **timeliness and completeness**: data must be current, up-to-date and provided in a timely manner
- **ontology:** relationships must be defined between data objects to represent a logical model of the assets within the built environment

An assessment of each option has been conducted in Table 5.

Opt	Standard taxonomy	Accuracy	Timeliness & completeness	Ontology
1	Simple schema	Limited accuracy	Immature verification and validation strategy	Does not include ontology
2	Standardised taxonomy to enable transparent data exchange	Limited accuracy	No governance to ensure data is up-to-date or complete	Does not include ontology
3	Standardised taxonomy to enable transparent data exchange	Accurate data	Up-to-date and complete	Includes ontology
4	Standardised taxonomy to enable transparent data exchange	Accurate data	Up-to-date and complete	Includes ontology
5	Standardised taxonomy to enable transparent data exchange	Accurate data	Up-to-date and complete	Includes ontology

Table 5 - Appraisal methodology using the data framework

Based on the above analysis, Option 3, 4 and 5 are preferred options to be taken forward.

Appraisal methodology using information transaction framework

The information transaction needs to be secure, high volume, near-real time flow of information. Key elements of information transaction are:

- **speed of transaction:** time it takes to transfer information from one party to another
- **transaction integrity**: accurate and complete transactions must take place in its entirety
- s**ecurity**: transactions, transport and storage, must be secure and protected to prevent any loss, unauthorised access or corruption during data transfer
- **functional requirement:** transaction requirements are clearly defined between the requestor and the data provider
- **volume:** this defines the volume of transactions between multiple parties
- **compatibility**: ability for transactions to be inter-operable and executed without any dependency on system or technology
- **automated**: the level of near real-time automation that can be achieved

An assessment of each option has been conducted in Table 6 against meeting the above standard minimum information transaction requirements.

Option	Speed of transaction	Transaction integrity	Security	Functional requirement	Volume	Compatibility (technology)	Automated
1	Non-real time	Need for manual validation and limited automation reduce trust	Security-minded with considerable reliance on supply chain and/or auditing required for implementation of measures	Primarily required to focus on construction sector, with limited uses across the other stages of economic lifecycle	Low volume transactions due to file-based data	Limited to specific technology systems	No automation
2	Non-real time	Need for manual validation and limited automation reduce trust	Security-minded with considerable reliance on supply chain and/or auditing required for implementation of measures	Able to support construction sector, with limited uses across the other stages of economic lifecycle	Low volume transactions due to file-based data	Limited to specific technology systems	No automation
3	Near real time	Ability to execute transactions to sufficient level of integrity	Security-minded to ensure transaction is secure enough for engineering, commercial and social purposes	Able to support multiple use cases across asset management lifecycle	High volume object transactions	Interoperable across multiple technology platforms	Automated
4	Near real time	Ability to execute transactions to sufficient level of integrity	Security-minded to ensure transaction is secure enough for engineering, commercial and social purposes	Able to support multiple use cases across asset management lifecycle	High volume object transactions	Interoperable across multiple technology platforms	Automated
5	Near real time	Ability to execute transactions to sufficient level of integrity	Security-minded to ensure transaction is secure enough for engineering, commercial and social purposes	Able to support multiple use cases across asset management lifecycle	High volume object transactions	Interoperable across multiple technology platforms	Automated

Table 6 - Appraisal methodology using the information transaction framework

Based on this assessment, options 3, 4 and 5 are to be taken forward.

Appraisal methodology using geographic extensibility and scalability across sectors

For the DBB programme to achieve the vision and fulfil the strategic objectives, the options must be extensible and scalable. Extensible is defined as the ability to add more functionality and scalable as the ability to accommodate growth.

Extensibility was assessed by determining if and how further functionality would be introduced to each option to accommodate new sectorial demands. The sectors selected were the high value sectors (HVS) of transport, utilities (energy and water), housing and social infrastructure.

Scalability was assessed by determining how growth in an option would be achieved as the extensibility introduced more functionality and the geographical reach increases from assets, to systems of assets, boroughs, cities, counties, regions and nations.

This analysis was made for each option, sector and geography to create a multi-dimensional evaluation shown pictorially in Figure 16.

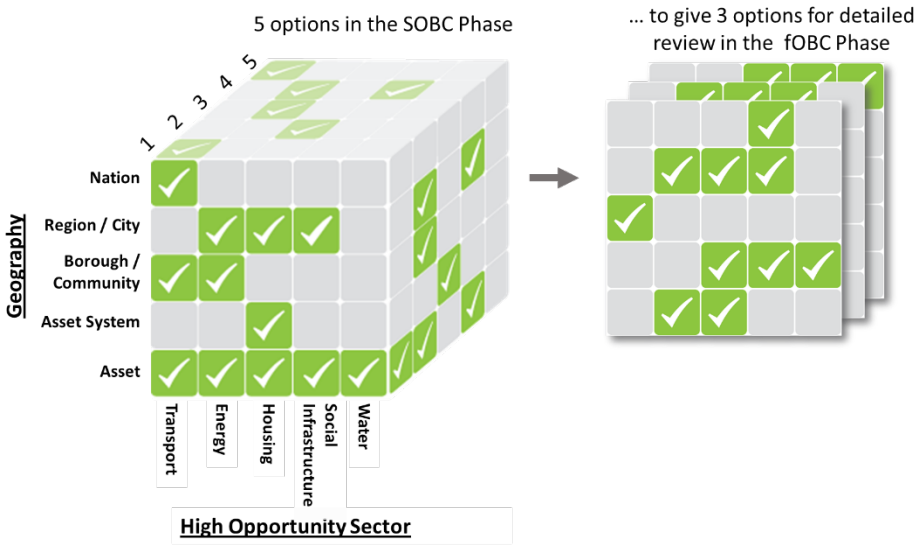


Figure 16 - Appraisal methodology for extensibility and scalability

Based on this appraisal option 3, 4 and 5 are to be carried forward.

3.3.3. Initial financial assessment

An initial assessment on each option was undertaken to establish the potential return on investment of the adoption and sustained used of the DBB programme outputs. It is necessary to ensure that any preferred way forward represents a good investment of public funds.

Very rough order of magnitude (VROM) estimates for costs and benefits have been developed for options 2, 3, 4 and 5, as shown in Table 7. The benefit estimates have been informed by relevant industry benchmarking and discussion with the DBB programme team. However, given that an information-enabled transformation of this type has not been carried out before, additional work will need to be completed to further develop the costs during the next phase of work.

Option	Description	Timescale	Total cost	Projected benefit
1	Do nothing: continue to support Level 2 'as-is'	N/A	Programme cost to date	N/A
2	Level 2 convergence:	2 to 4 years	£5m to £10m	£0.2bn to £1bn
3	Integration environment focused on building and strategic networks	3 to 5 years	£54m to £68m	£9.1bn to 29.3bn
4	Integration environment focused built environment & city services	5 to 7 years	£176m to £220m	£14.9bn to £85bn
5	Integration environment and platform focused on built environment, city & consumer services	7 to 15 years	Integration environment: £750m-£1bn Platform development: £8bn to £14bn	£75bn to £120bn

Table 7 - Financial appraisal using value for money appraisal

The following assumptions have been made in determining the potential costs:

- option 5 has 2 elements:
    - the underlying integration environment comprising of the business process models, the reference data library, population of the data models and the facilities needed to manage this
    - the collection and validation of the asset reference data, and the development/management of the SW platform ecosystem. In order to realise the benefits a platform will be needed. No decision has been made or suggested to whom should develop the platform at this stage, only a platform will be required
- the end date for each option is based on the upper range of the timescales provided in the economic case options summary in this document
- indicative day rates range between £700 - £1650.
- real discount rate of 3.5% has been applied to these costs as per Green Book guidance
- all figures are VROM and are based on current understanding of the scope and associated activities of each option. These will need to be further developed during the next phase of the programme
- benefits estimates have been derived by analysing relevant case studies, limited benefits logic and modelling. More detailed benefits logic and modelling will need to be developed in the next phase of the programme
- costs are based on industry benchmarking, this includes:
    - resource costs (FTE)
    - hardware
    - software
    - infrastructure data collection for proof of concept and pilot activities

3.3.4. Benefits development approach

In order to assess each of the DBB options, a forward and reverse path was considered. Forward started with the components of DBB, mapping these to the benefits foreseen. For reverse, benefit potential identified from research is decomposed to identify the components needed to realise. Both paths are consolidated in the overall analysis.

The steps taken in this benefit tracing are:

- **work packages delivered by DBB** that would enable improved information-enabled decision making
- **information-enabled industry capabilities** that would be created through the identified work packages
- **commercial services** would need to be provided to realise the identified information-enabled industry capabilities
- **change** that will occur as a result of utilising the new capability and commercial services
- **benefits,** the socio-economic benefit(s) that will result from the change. Benefits were categorised as either quantifiable economic benefits that contribute to increase UK productivity and growth or a qualitative strategic benefit that positively impacts the UK society

The quantum of benefit is derived by:

- determining the total annual economic value of a benefit areas
- deriving the amount that can be attributed to the DBB programme
- profiling the benefit over a period

The forward path of this process is shown in the Figure 17 and an example of service provision is included in Figure 18. Benefits logic maps and further information on how the benefits were calculated are provided in Appendix H.

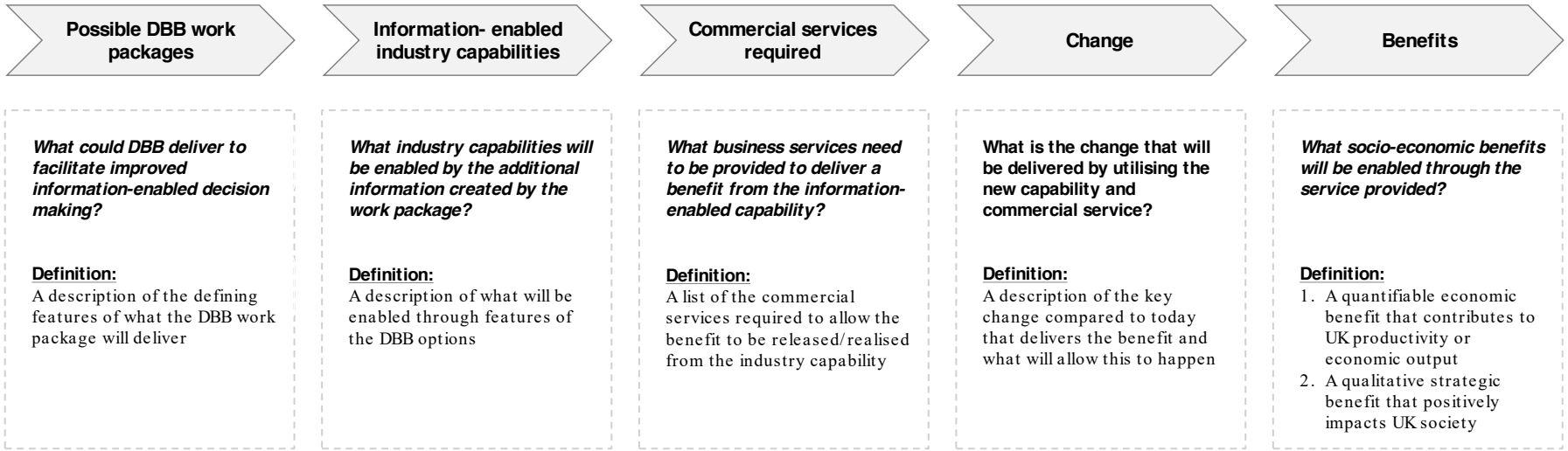


Figure 17 - Benefits framework (forward path)

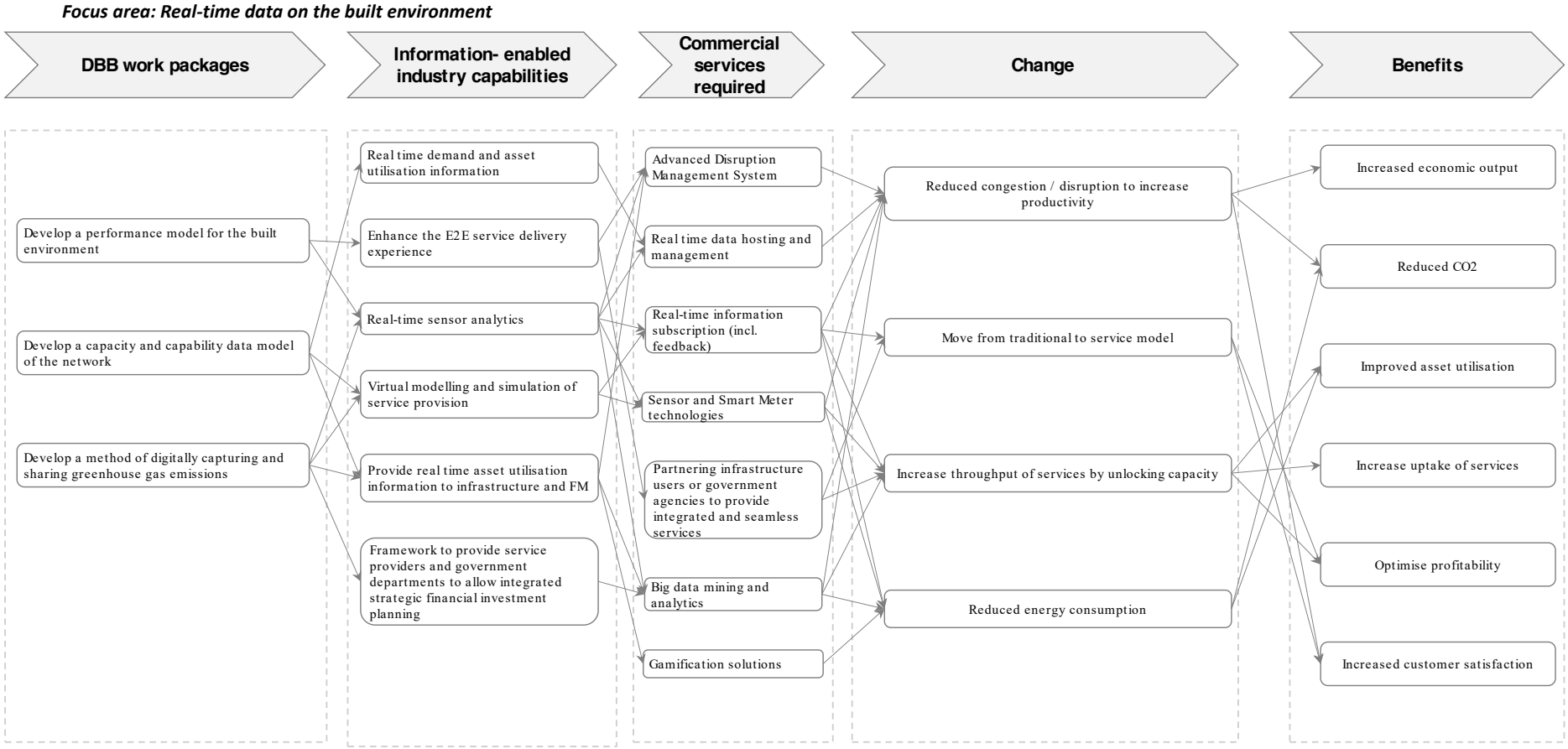


Figure 18 – Example of benefits framework for service provision

Further details of the benefits framework are included in Appendix H.

3.4. Summary

The economic appraisal has listed 5 options in accordance with the green book guidance. Each of the 5 options has been subjected to an evaluation based on non-financial appraisal including: the data framework, information transaction and scalability/ extensibility and a financial assessment of value for money. This has shown that options 3, 4 and 5 should be selected for further investigation in the next stage of the programme.

It has also indicated that Option 2, Level 2 Convergence, where the bridge between existing Level 2 and future Level 3 is defined, should commence immediately. It is a pre-requisite and necessary step in the development and implementation of Option 3, 4 and 5. It would not be abortive work and would help de-risk the subsequent stages.

4. Commercial Case

4.1. Introduction

The Commercial Case focuses on the procurement methodology of the preferred option. Given that at this stage an option has not been selected, the Commercial Case will provide a high-level outline of the proposed approach

The SOBC Commercial Case investigates the following:

- the commercial strategy
- the procurement strategy
- contract management

The commercial case concludes there is a gap in the market for the digital transformation of the built environment and the UK has the capability to grow this sector at a global scale. This capability needs capacity growth to address our domestic needs, and to grow the knowledge and commercial sectors export potential. The potential for the private sector is significant as this global market develops driving the commercialisation of innovation in new products and services.

4.2. Commercial strategy

There is significant commercial opportunity for UK companies and research institutions with the DBB programme. In order to unlock these opportunities, it will be necessary to build a scalable and extensible foundation ontology and integration framework that will allow the systems and systems-of-systems to be securely converged. As this is developed, Proof of Concepts will be necessary to confirm the methods suggested will fulfil their objectives. These Proof of Concepts will need greater scaling to evaluate with Pilot applications in High Value Sectors. This will enable industry and society to stress test the development and confirm benefits.

In order to increase adoption, the market entry strategy will need to incentivise the public and private sector clients, and suppliers to work as delivery partners with the DBB programme with:

- regulation changes (e.g. reporting regulations)
- policy changes (e.g. planning policy)
- procurement mandates (similar to the level 2 BIM mandates)
- budget incentives (e.g. taxation schemes)

Incentivising schemes will be developed in consultation with HMRC and HM Treasury, covering a package of tax breaks and available funding with eligibility criteria linked to compliance with the DBB programme outputs.

With a combination of pilots, support and incentives, a tipping-point will be reached. From here the private sector will be able to commercialise the applications and the digital transformation of the built environment will accelerate domestically and globally.

4.3. Procurement strategy

The procurement strategy for programme implementation will be developed in more detail once the option is selected. This will involve a range of commercial and technical development activities and associated supply chain engagement.

A multidisciplinary team with extensive experience in the relevant areas has already been identified, and can be appointed on securing financial authority for the creation of the procurement strategy.

The engagement and tender process will be supplemented by input from the programme's own Client Design Authority (CDA).

4.4. Contract management

The contract management strategy for the overall programme will be developed during the outline business case (OBC) stage.

5. Financial Case

5.1. Introduction

The Financial Case provides an overview of the anticipated capital and revenue requirements, based on the shortlist of options from the Economic Case.

The Financial Case investigates the following:

- funding and affordability
- projected costs

Public and potentially private investment in the programme is required to deliver the minimum necessary requirements for meeting the appraisal criteria for each of the shortlisted options, as outlined in the Economic Case.

5.2. Funding and affordability

Funding for the DBB programme will be forthcoming from both the public and private sector. It is suggested that future stages of the programme are focussed around a Centre of Excellence for research needed and realisation of the Industrial Strategy. This could be used as a vehicle for attracting private sector investment to enable proof-of-concepts and pilots. Further confirmation of the funding requirements for the subsequent phases of the DBB programme will be undertaken in the OBC.

Private sector funding will be determined by the market entry strategy set out in the Commercial Case.

5.3. DBB projected costs and benefits

VROM costs are based on estimated organisation charts and IT and hardware estimates for options 2, 3, 4 and 5 shown in Table 8. The cost estimates have been informed by relevant industry benchmarking, however given that an information enabled transformation of this type has not been undertaken before additional work will be required to further develop the costs during the subsequent project stagesn

Option	Description	Timescale	Total cost	Projected benefit
1	Do nothing: continue to support Level 2 'as-is'	N/A	Programme cost to date	N/A
2	Level 2 Convergence:	2 to 4 years	£5m to £10m	£0.2bn to £1bn
3	Integration environment focused on building and strategic networks	3 to 5 years	£54m to £68m	£9.1bn to 29.3bn
4	Integration environment focused built environment & city services	5 to 7 years	£176m to £220m	£14.9bn to £85bn
5	Integration environment and platform focused on built environment, city & consumer services	7 to 15 years	Integration environment: £750m-£1bn Platform development: £8bn to £14bn	£75bn to £120bn

* Discount rate of 3.5% has been applied

Table 8 - Financial appraisal using value for money analysis

6. Management Case

6.1. Introduction

The Management Case demonstrates that the preferred options are capable of being delivered successfully, in accordance with recognised best practice. At this stage, due to the level of maturity of design and development, the Management Case provides a high-level outline.

The Management Case investigates the following:

- outputs
- management approach
- risks and dependencies

It is proposed that a Centre of Excellence will be set up early in the development of this programme. This Centre of Excellence will allow the delivery of multiple proofs-of-concept during the next stage of the programme, reducing the risk for future investment requirements and provide confidence of benefits realisation.

6.2. Outputs

The DBB programme, in conjunction with a government-backed industry engagement and adoption strategy, will set to achieve the outputs shown in Figure 19.

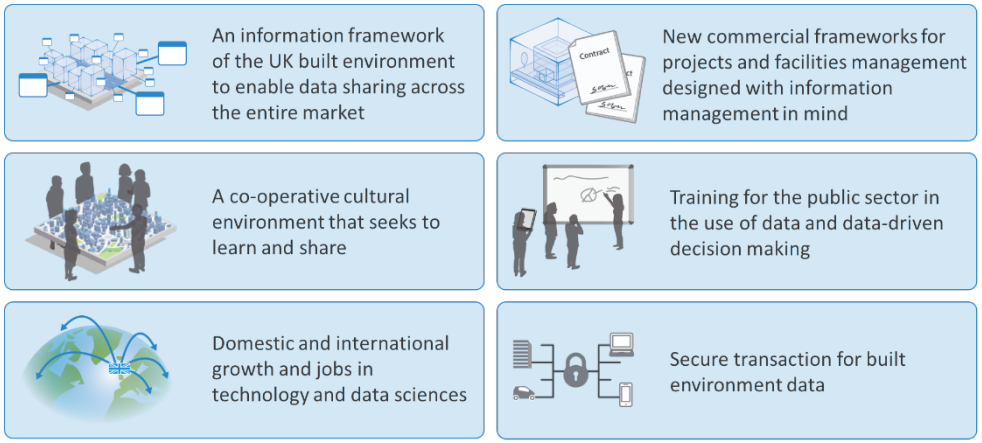


Figure 19 - DBB programme outputs

An information framework of the UK built environment to enable data sharing across the entire market: the DBB programme will create a mature information framework, to enable information flow across the whole lifecycle of built environment. This will involve the development of a standard information model that will be extensible across multiple geographies and sectors.

A co-operative cultural environment that seeks to learn and share: the DBB programme will foster a cultural environment which is collaborative and seeks to learn and share, enabling and incentivising behavioural change and a common language to facilitate greater collaboration. Enabling information flow through the stages of the lifecycle to those who plan future strategic financial investments.

Domestic and international growth and jobs in technology and data sciences: the development of a new information framework, high volume transactions and exponential growth in built environment data, will require new skills and technologies to analyse and explore the data. The DBB programme will serve as a powerful lever to drive future innovation, competitiveness and growth within the domestic and international digital economy.

New commercial frameworks for projects and facilities management designed with information management in mind: establishing the appropriate commercial frameworks for projects enabling procurement that addresses and incorporates information management to encourage collaborative working and information transactions through the full asset lifecycle.

Training for the public sector and capacity in the private sector in the use of data and data-driven decision making: development of information framework, standards and new technologies, will require training the public sector client with the new skillsets. New training and development will introduce new data management techniques such as data requirements, operational methods and capacity modelling.

Secure and trusted transactions of built environment data: enabling information to transfer through the full lifecycle with appropriate levels of trust and security. It will include development of near real-time high-volume information transactions that are secure enough for commercial, engineering and social purposes.

6.3. Management approach

The DBB programme will enable far-reaching benefits across the UK's infrastructure and infrastructure-related service industries. Successful deployment will require a robust, innovative and collaborative business change strategy.

The core purpose of the business change strategy will be to drive the quality of the DBB programme design and implementation processes through engagement with government, industry and the third sector.

As the programme progresses, the focus of both the industry engagement and industry adoption strategy will shift to mobilising cross-sector stakeholders to become accountable for adoption and benefits realisation.

6.4. Programme delivery partners

The delivery of the programme depends on the collaboration and alignment of the objectives of the partners involved in the programme as part of the 'Bridgehead' with government and academia. Table 8 describes the main objectives of the key partners of the programme.

Table 9 - DBB delivery partners

Partner	Delivery Involvement
DBB Management Board	• leading the DBB programme management, focusing on the development, approval and sign off for the business case
Government	• continued involvement and support, either financially or involvement in potential pilot programmes/PoC • implementation of appropriate market-entry strategies • design and implementation of trust and security requirements
Centre of Excellence	• developing 'research requirements' landscape, with input and engagement from stakeholders and in partnership with the academic community • informing R&D funding requirements and appropriate funding mechanisms to deliver the R&D programme • maintaining a view of the 'state of the art' of research, both nationally and internationally • synthesizing relevant research outputs and feed them into the development of the wider DBB strategy • wider public engagement, to understand needs and inform outcomes
Private Sector	• establishing public-private partnerships • developing private sector commercial services market • involvement in PoC and pilots programmes
British Standard Institute	• developing new British standards allowing an information-standards-enabled market for built environment information and associated services • aligning standardisation nationally and internationally • collaborating with International Standards Bodies to ensure benefits across all involved countries
Professional Institutions	• support and acting as a catalyst across industry • facilitating cultural change • informing education of future generations of professionals
Academia	• developing training programme outline for the public sector in the use of data and data-driven decision making • bringing key stakeholders of digital engineering across academia together - collaboratively developing next steps for a consistent strategy for skills and training

6.5. Risks and dependencies

The DBB programme dependencies will be managed by the DBB PMO. Identifying dependencies and understanding their implication on investment and benefits realisation is a critical input into the development of the next stage of the programme. This is detailed in

Table **10**.

Dependencies have been identified based on their potential to impact benefits realisation, whether through an impact on technical delivery, industry engagement, or industry adoption. Though dependencies have been categorised to align with the individual work streams within the CDA they will need to be addressed by the programme as a whole.

The following log of DBB dependencies includes an assessment of the impact on benefits realisation, with proposed mitigating actions as identified by the CDA, and included in the DBB Programme Brief.

Table 10 - Risks and dependencies

Dependency	Impact on benefits realisation	Potential mitigation
Culture		
Commitment to the DBB programme by demand /supply side	Necessary to lever investment and create critical mass	Early proof-of-concept
Clients and suppliers incentivised to use shared data	Low volumes of data exchange constrain ability of DBB model to reach critical mass	Promotion of robust business-ready DBB standards and data sets. Targeted incentives within specific business sectors
Demonstration of benefits at an early stage of implementation	DBB focused on short term deliverables falls short on delivery of L3 benefits	Strategic focus on investment in common business process across sector
Impact of industry change programme	Necessary to accelerate adoption and create critical mass	Keep DBB simple, scalable and focused on achieving vision. Investment in industry change programme
Commercial		
Creation of critical mass in DBB markets	Limit on extent to which clients can secure benefit through their supply chains	Design of DBB to deliver benefit to the supply chain and clients. Interventions / incentives to encourage take-up. Scalable solutions
Assured consistent sources of demand	Disincentive to investment by public sector in DBB business model	Accelerated adoption of DBB business principles by utilities and other sectors that can be influenced by government
Ability to monetise data value chains	Creation of revenue-generating value chains associated with DBB to attract investment into industry transformation	Design business process to deliver incremental benefit to participants

Enabling processes and tools acceptable to the market, e.g. contracts	DBB unlikely to deliver benefits unless 'investable and insurable'	Use precedent from other digitally-enabled sectors
Ability to sustain DBB and non-DBB business models in parallel	Availability of non-DBB business model delays transition to new ways of working	The DBB programme has clear steps towards sector-wide adoption of DBB transactions aligned to mandate

Dependency	Impact on benefits realisation	Potential mitigation
Technical		
Sector ability to identify and agree information requirements	Necessary to build the infrastructure for digital transactions	Early proof-of-concept. Focus on minimum viable datasets for high volume transactions. Expectations management with respect to scale of transactions
Data interoperability. Sector alignment with data management	Inability to enable trusted digital transactions	Resolution of data interoperability as a fundamental building block of DBB
Access and rights to use data at an acceptable price. Controls over the collection, storage and use of data	Risks uneven adoption of DBB within a sector	Development of IP model that supports 'data commons' and the creation of an open data market. Development of a managed data market, potentially with regulatory oversight

Dependency	Impact on benefits realisation	Potential mitigation
Security		
Secure solutions that are aligned to business process and customer journey	Essential security required to underpin digital transactions must support efficient process	DBB solutions defined as secure by design and secure by default
Secure solutions that address risks associated with data aggregation	Ability to access large-scale data essential for L3 benefits	DBB data management solutions defined as secure by design and secure by default

7. Conclusions

The SOBC concludes, through the 5 cases of the Green Book approach:

Strategic case: There is a strong case for change. The previous work of DBB has proved the validity of the approach. The SOBC work has confirmed its wider applicability and overall link to improved productivity in a way that enables the innovation, skills, infrastructure, procurement, energy and regional growth pillars of the Industrial Strategy Green Paper.

Economic case: The economic return makes investment worthwhile. There is an opportunity to make changes in government-funded capital spend that have a positive impact on the long-run operating costs of an asset. This will improve operations on existing assets to deliver better services outcomes and to optimise services dependent upon government-funded infrastructure to meet demand. These benefits are amplified when modelled across multiple services such as housing and transport, translating to a quantified and improved social value. The return cannot be achieved without government support to prime the market. Options for intervention have been identified, and will be further developed as the programme progresses.

Commercial case: DBB will grow the UK's existing information-related skills and services market as a world-leader with export potential. The SOBC work has identified a gap in the market for new commercial services in the provision of infrastructure optimisation and investment modelling, dependent upon successful adoption of an information standard. The previous work of DBB has already proven this to be the case in construction, with UK firms leading the way.

Financial case: DBB's work is a key enabler for realising the objectives of both the construction and smart city themes within the Industrial Strategy. The early-stage work of DBB to prime the market is best delivered through R&D funding associated with realisation of the Industrial Strategy, directed into a centre of excellence that acts as a vehicle for attracting private sector investment.

Management case: DBB's work requires continuation of a Green Book approach, combined with the DBB programme's System Engineering approach to implementation. This will provide a clear alignment between the overall policy objectives of Government, sectors and beneficiaries, the development of a private sector commercial services market, information standards, skills and tools, required sensing and monitoring technology; all delivered in a security and trust framework.

8. Recommendations

The recommended next steps for the DBB programme are:

1. Shortlist the preferred Level 3 option for further development during an Outline Business Case. This could include further development around these themes:
    a. engaging with industry, government and academia to inform and challenge
    b. developing a research bridgehead
    c. identifying the necessary standards, tools and skills.
    d. how product and service certification could be achieved, for example with an equivalent to 'RegTech'?
    e. integration with the other aspects of the DBB programme, including manufacturing
    f. developing Proof of Concepts and Pilots
2. Seek funding to develop a short-term Level 2 (Convergence) programme to leverage the investments made in BIM, sensors and measurement and digital city services
3. Determine the best manner in which the preferred option can be further developed and delivered
4. Communicate progress regularly and engage with industry, government and academia to ensure a managed industry change process

Glossary

Term	Definition
Actor	An actor is a participant in an action or process
Assets systems	An asset system is a coordinated system of assets i.e. the road network
Beneficiary groups	Beneficiary groups are the relevant stakeholders within each stage of the built environment economic lifestyle
Building Information Modelling	Building Information Modelling (BIM) is a process for creating and managing information on a construction project and to continue across the project lifecycle. It is a set of technologies, processes and policies enabling multiple stakeholders to collaboratively design, construct, operate and maintain the built environment
Built Environment	Built Environment encompasses all forms of building (housing, industrial, commercial, hospitals, schools, etc.), and civil engineering infrastructure, both above and below ground. It includes not only buildings, but other managed landscapes between and around buildings, such as parks. It also includes infrastructure that supports service provision such as transportation networks, utilities networks, flood defences, and telecommunications
Built environment economic lifestyle	Built environment economic lifecycle encompasses the planning, designing and building of assets (CapEx), the maintenance and operation of assets (OpEx), the optimisation of supply and the shaping of demand (Service Provision), the use of assets to improve quality of life (Social), and the planning of new investments in the Built Environment (Strategic Financial Investment Planning)
Capabilities	A capability is a combination of people, process and technology, enabled by information that is value-creating in its outcome
Capacity	Capacity is the specific ability of an entity (person or organisation) or resource, measured in quantity and level of quality
Capital Expenditure (CapEx)	Capital expenditure, or CapEx, are funds used by an organisation to acquire or upgrade physical assets such as property, industrial buildings or equipment
Centre of Excellence for DBB	The main centre for the delivery of the DBB programme
Client Design Authority (CDA)	The Client Design Authority (CDA) is a group of industry experts responsible for overseeing the DBB programme's progression
Commercial framework	Commercial framework is a structured approach to defining and comparing alternative commercial and financial arrangements
Commercial services	Commercial services combine one or more capabilities to deliver a service which can potentially be monetised e.g. digital modelling and simulations
Common data models	Common data models are standardised definitions of how system solutions and technologies represent resources and their relationships
Common information standards	Common information standards define how managed elements in an IT environment are represented as a common set of objects as well as defining the relationships between them

Construction productivity	Construction productivity is output per worker in the construction sector
Data integrity	Data integrity is the maintenance of, and the assurance of the accuracy and consistency of, data over its entire life cycle, and is a critical aspect to the design, implementation and usage of any system that stores, processes, or retrieves data
Digital Built Britain	Digital Built Britain (DBB) is the programme and organisation combining technology with the internet of things (providing sensors and other information), advanced data analytics and the digital economy to enable us to plan new infrastructure more effectively, build it at lower cost and operate and maintain it more efficiently. This will enable citizens to make better use of the infrastructure we already have
Digital economy	Digital economy is an economy that functions primarily by means of digital technology
Digital twinning platform	A digital twinning platform uses data from sensors installed on physical objects to represent their near real-time status, working condition or position
Economic Productivity	Productivity is an economic measure of output per unit of input. Inputs include labour and capital, while output is typically measured in Gross Domestic Product (GDP). Productivity measures may be examined collectively (across the whole economy) or viewed industry by industry
Gross Domestic Product (GDP)	Gross Domestic Product (GDP), is the monetary value of all the finished goods and services produced within a country's borders in a specific time period. It can be calculated on an annual basis or quarterly basis. GDP is commonly used as an indicator to measure the economic health of a country
Geographic Information System (GIS)	A Geographic Information System (GIS) is a computer system for capturing, storing, checking, and displaying data related to positions on Earth's surface. GIS can show many different kinds of data on one map. This enables people to more easily see, analyse, and understand patterns and relationships
High value sectors	High value sectors (HVS) are those sectors in which DBB is expected to have the greatest positive impact (transport, energy, housing, social infrastructure, water)
Information economy	Information economy is an economy that has an increased emphasis on informational activities and information industry
Infrastructure	Infrastructure is part of the basic physical systems of a business or nation, including but not limited to transportation, communication, sewage, water and electric systems
International Organisation for Standardisation	The International Organisation for Standardisation is an international standard-setting body composed of representatives from various national standards organisations
Internet of Things	The Internet of Things (IoT) is the interconnection via the Internet of computing devices embedded in everyday objects, enabling them to send and receive data
Manufacturing Technology Centre	The Manufacturing Technology Centre (MTC) based in Coventry is the organisation through which potential DBB products will be delivered
Market entry strategy	Market entry strategy encompasses those activities associated with bringing a product or service to a

	targeted market. During the planning stage, a company will consider the barriers to entry, the costs of marketing, sales and delivery, and the expected outcome of entering the market
Natural environment	Natural environment includes the climate, weather, and natural resources that affect human survival and economic activity
Near real-time transaction	Near real-time transactions are transactions in which there are no significant delays between the occurrence of the transaction, the processing of the transaction, and the completion of the transaction
Operational Expenditure (OpEx)	Operating expenditure, or OpEx, is an expense an organisation incurs to maintain and operate its business operations. OpEx includes expenses such as rent, equipment, inventory costs, marketing, payroll, insurance and funds allocated to R&D
Options Appraisal Framework	The Options Appraisal Framework is a framework that assists with the selection of the recommended options, or preferred way forward
Outline Business Case	The Outline Business Case (OBC) is one of 3 business cases as part of HM Treasury's 5 case model. The Outline Business Case details the appraisal work on the short listed options from the Strategic Outline Case (SOC) and the selection of the preferred option to be taken through a procurement stage in the Full Business Case (FBC)
Proof of concept	A proof of concept (POC) is a demonstration, the purpose of which is to verify that certain concepts or theories have the potential for real-world application. DBB proof of concepts, in the form of work packages, will be delivered through the Manufacturing Technology Centre
Public-Private Partnership	A public–private partnership is a cooperative arrangement between 2 or more public and private sectors, typically of a long-term nature
Reference data	Reference data defines the set of permissible values to be used by other data fields
Service Provision	Service Provision is the delivery of services demanded by a business or person in exchange for acceptable compensation
Service	A service is a system supplying a public need such as transport, communications, or utilities such as electricity and water
Smart Cities	A smart city is an urban development vision to integrate information and communication technology (ICT) and Internet of things (IoT) technology in a secure fashion to manage a city's assets. A smart city is promoted to use urban informatics and technology to improve the efficiency of services
Strategic Financial Investment Planning	Strategic Financial Investment Planning represents the planning of new investment in the Built Environment i.e. new schools or new strategic roads
System	A system is a set of things working together as parts of a mechanism or an interconnecting network
System Engineering Framework	The System Engineering Framework is a conceptual blueprint, visually articulating the ‘case for change’ and the ambitions of the DBB programme
TotEx	Total Expenditure, or TotEx, in context of this work, refers to the combined Capital expenditure (CapEx) and Operating expenditure (OpEx)

Value for money	Value for money evaluates the estimated costs and benefits to determine whether a project represents an optimum use of resources
Very Rough Order of Magnitude	A Very Rough Order of Magnitude estimate is an approximation of the cost of a program, project, or operation
Work package	A work package is a project or sub-project that the DBB Programme will deliver through the Manufacturing Technology Centre (MTC)

Appendices

A – Policy Alignment

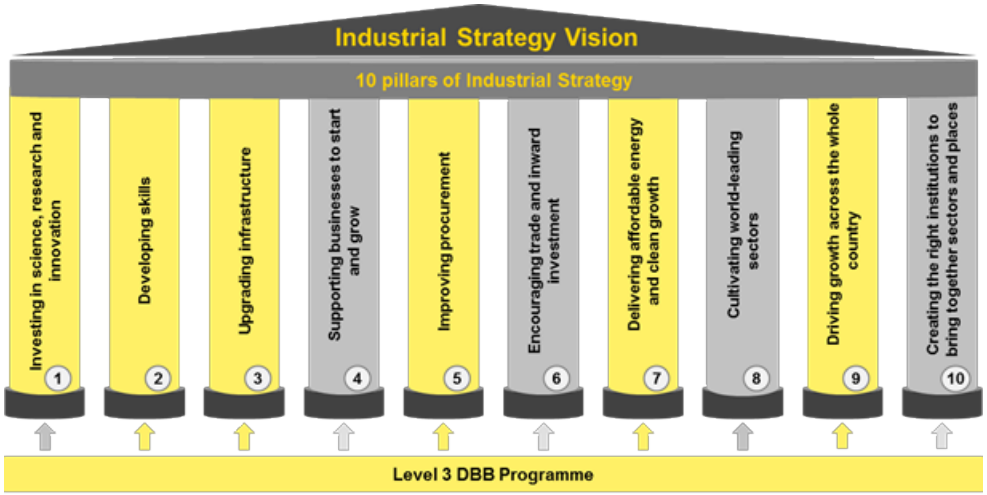
The DBB programme supports the objectives of several government departments:

A.1. BEIS: Building our Industrial Strategy

The Department for Business, Energy and Industrial Strategy (BEIS), in its Building Our Industrial Strategy green paper sets a focus on the productivity challenge, in particular improving living standards and strengthening the economy.

BEIS articulates the role of the Industrial Strategy as an enabler for more productive and better balanced economies and identifies ten pillars for driving forward the Industrial Strategy. Below describes how this programme can directly support 6 of these pillars by facilitating research, upgrading infrastructure, driving growth across the whole country, and delivering affordable energy and clean growth.

Beyond the direct support that this programme anticipates to 6 pillars, there are secondary focus areas in which this programme can support all of the pillars from the Industrial Strategy.



Primary Focus Areas	
Industrial Strategy Pillar	The Contribution of the DBB Programme
Investing in science, research and innovation – we must become a more innovative economy and do more to commercialise our world leading science base to drive growth across the UK.	To become a more innovative economy requires the ability to seize new opportunities and adapt to change. Developing the appropriate frameworks (for example data models and support for commercial exploitation) can enable the UK to drive the commercialisation of data and lead in the information based optimisation of energy storage and networks.
Developing skills – we must help people and businesses to thrive by: ensuring everyone has the basic skills needed in a modern economy, building a new system of technical education to benefit the half of young people who do not go to university, boosting STEM (Science, Technology, Engineering and Maths) skills, digital skills and numeracy and raising skill levels in lagging areas.	The right environment (e.g. open data, appropriate information specification) and stimulus to apply information in decision making can spark growth in innovative start-ups and SMEs. An economy with more innovative start-ups will require more highly skilled people. Much of facilities management work is seen as requiring relatively low levels of technical skill. Extending information-driven decisions during operations, maintenance and facilities management can drive an increase in the number of high-skill roles.
Upgrading infrastructure – we must upgrade our standards of performance on digital, energy, transport, water and flood defence infrastructure, and better align central government	Competitiveness: basing decision making on the right cross-sector, all-source, information can support optimised investment to enable the UK to realise improved connectivity between people, employment and services. Improving

infrastructure investment with local growth priorities.	connectivity and energy costs in turn improves our attractiveness for inward investment. Having the appropriate environment and frameworks to support strategic investment planning will enable the best return on the funding identified in the National Productivity Investment Fund, which includes £2.6 billion for "improvements in travel links to reduce journey times and help deepen labour markets". Without an inter-modal understanding of the logic and capability of, for example, the transport solutions for a region, there are significant barriers to determining the most effective investment approach. Productivity: this government will enable councils to address local issues, empowering and funding them to fund the infrastructure to allow development on marginal sites. Overcoming the barriers in aligning planning for infrastructure with planning for housing and industry will be key in addressing areas with acute housing needs. The government is clear that increasing productivity will mean working smarter rather than harder. Working smarter will require innovation and this will, in part, be enabled by a £1.7 billion Accelerated Construction programme. New entrants (innovative private sector partners and offsite manufacturers) could bring new skills and rapid methodologies and these approaches will require a solid information foundation.
	Resilience: increasing volumes of data are being made available, aggregated and applied in automated ways across more integrated systems. In this context there is an opportunity to increase the resilience of the UK by ensuring that our systems and networks are secure by design and, in applying a complete understanding of the capability of networks of assets, optimise our infrastructure investment – for example, to drive a more resilient approach to environmental, demographic and security changes.
Improving procurement – we must use strategic government procurement to drive innovation and enable the development of UK supply chains.	The government is committed to exploring new public-private partnerships under PF2 and to the rollout of a balanced scorecard in construction. These, along with broad changes in the nature and extent of the use of information, present an opportunity to enable innovation in procurement (e.g. procuring outcomes rather than outputs) and efficiency through the built environment lifecycle, for example by establishing the right levels of trust throughout the information lifecycle.
Delivering affordable energy and clean growth – we need to keep costs down for businesses, and secure the economic benefits of the transition to a low-carbon economy.	Far greater sums are invested in maintaining and enhancing our existing built environment than in building new assets. Given the need to keep costs down for businesses, a focus on optimisation in the operations phase is where the greatest scope for efficiency lies. With the government committed to setting a total carbon price in 2021/22, there is an opportunity to realise increased clarity

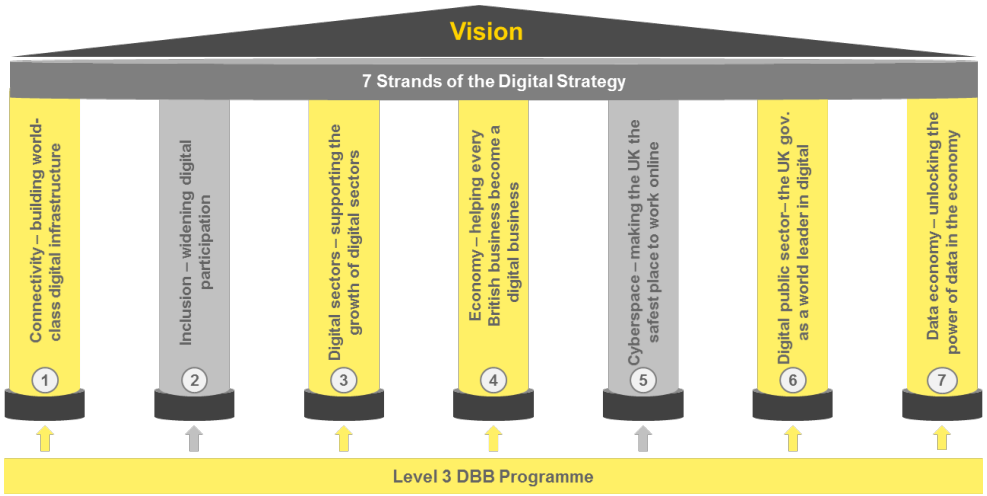
	relating to total lifecycle costs if the right information environment is created. Optimisation (e.g. through smart grids) and artificial intelligence can help shape demand and supply curves and drive further efficiencies. As new technologies are adopted, a cross-sector approach integrating information across the full lifecycle will increasingly be required to drive efficiencies.
Driving growth across the whole country – we will create a framework to build on the particular strengths of different places and address factors that hold places back – whether it is investing in key infrastructure projects to encourage growth, increasing skill levels, or backing local innovation strengths.	The government is empowering cities, regions and local authorities to take the decisions on investment to encourage growth. To enable better decision making the government will support moves to establish better local decision-making structures for infrastructure planning. Regional bodies such as Midlands Connect and Transport for the North will require the right information enablers to take full advantage of funds such as the Housing Infrastructure Fund and £1.1 billion of funding for local roads and public transport networks. Regional bodies can also show increased accountability through closer connections between the built environment and associated information.

The contribution of the DBB programme to the Industrial Strategy (Primary Focus Areas

Secondary Focus Areas Industrial Strategy Pillar	The contribution of the DBB Programme
Supporting businesses to start and grow – we must ensure that businesses across the UK can access the finance and management skills they need to grow, and we must create the right conditions for companies to invest for the long term.	A long-term approach to connecting people, employment and services can drive productivity improvements, and in turn can help us to retain our attractiveness as a place to start and grow a business. Addressing short-term thinking, for example, by empowering service operators and enabling an integrated view and understanding across both supply and demand, can support a more business-centric approach that provides the optimal local environment for inward investment (e.g. by addressing transport infrastructure weaknesses, supporting the right local skills markets, industries and supply chains).
Encouraging trade and inward investment – government policy can help boost productivity and growth across our economy, by increasing competition and helping to bring new ways of doing things to the UK.	Empowering the right institutions and setting the right information environment can drive new commercial models and increase transparency and reduce risk through the asset lifecycle. These in turn can act as a spur to increased inward investment. Further, just as policy interventions in Level 2 BIM have acted as a market stimulus, advancements can stimulate the market to generate new export opportunities
Cultivating world-leading sectors – we must build on our areas of competitive advantage, and help new sectors to flourish, in many cases challenging existing institutions and incumbents.	The government's devolution agenda affords the opportunity for institutions such as local councils to take a service operator approach to the provision of public services. By adopting such approaches as the procurement of public service outcomes rather than outputs, cross-sector service operators can drive transparency, accountability and address regional productivity imbalances by creating a demand for new business services. Fostering new business service opportunities at the local level can in turn drive skilled job creation and local competition. Ultimately, opportunities for new business models can enable private sector growth both at the local level and through exporting those services.
Creating the right institutions to bring together sectors and places – we will consider the best structures to support people, industries and places. In some places and sectors there may be missing institutions that we could create, or existing ones we could strengthen, be they local civic or educational institutions, trade associations or financial networks.	Given the need for productivity improvements – which can have the greatest impact in relation to the existing asset base – promoting increased professionalisation in asset management can support competition, innovation and help drive exports. Further, by addressing challenges associated with information specification, interoperability / integration and security, the Level 3 DBB programme can enable system operator models to be applied in the built environment.

The contribution of the DBB programme to the Industrial Strategy (Secondary Focus Areas

A.2. Department for Digital Culture, Media & Sport (DCMS): UK Digital Strategy

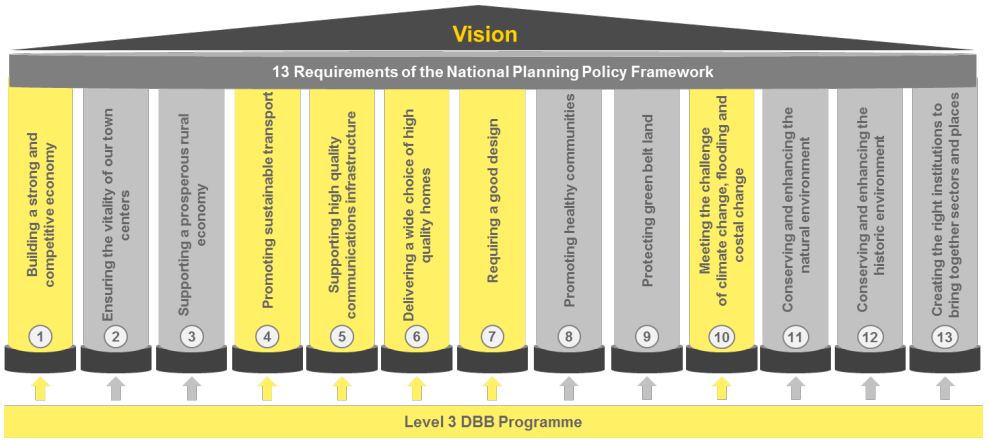


The DBB programme supports the Digital Strategy

Strands of the Digital Strategy	The Contribution of the DBB Programme
Connectivity – building world-class digital infrastructure	Digitally transforming built assets
Digital sectors – supporting the growth of digital sectors	Providing the datasets and connectivity to support the development of new digital sectors such as autonomous vehicles
Economy – helping every British business become a digital business	Encouraging and enabling businesses to use asset data to drive innovation and productivity
Digital public sector– the UK gov. as a world leader in digital	Harnessing data to deliver better public services at lower cost

The contribution of the DBB programme to the Digital Strategy

A.3. Ministry of Housing, Communities & Local Government: National Planning Policy Framework



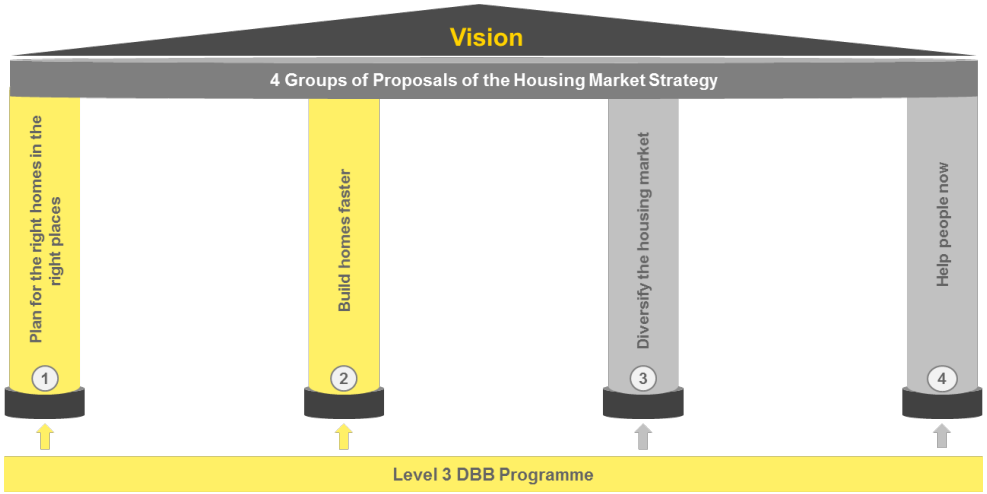
The DBB programme supports the National Planning Policy Framework

Requirements of the National Planning Policy Framework	The Contribution of the DBB Programme
Building a strong and competitive economy	Better planning infrastructure investment to meet the needs of businesses and encourage economic growth
Promoting sustainable transport	Local authorities to ensure that built infrastructure can support sustainable development and use of sustainable transport modes
Supporting high quality communications infrastructure	Integrated planning to ensure local plans support the expansion of the digital communications network

Delivering a wide choice of high quality homes	Boost supply of housing through better integrated planning on development sites and create sustainable, inclusive and mixed communities
Requiring a good design	High quality and inclusive planning and design to ensure sustainable development and reduce whole life cost
Meeting the challenge of climate change, flooding and costal change	Improve planning to support reduction in greenhouse gases and associated infrastructure, and enable a broad and integrated view of the built environment and the natural environment

The contribution of the DBB programme to the National Planning Policy Framework

A.4. Ministry of Housing, Communities & Local Government: Fixing our broken housing market

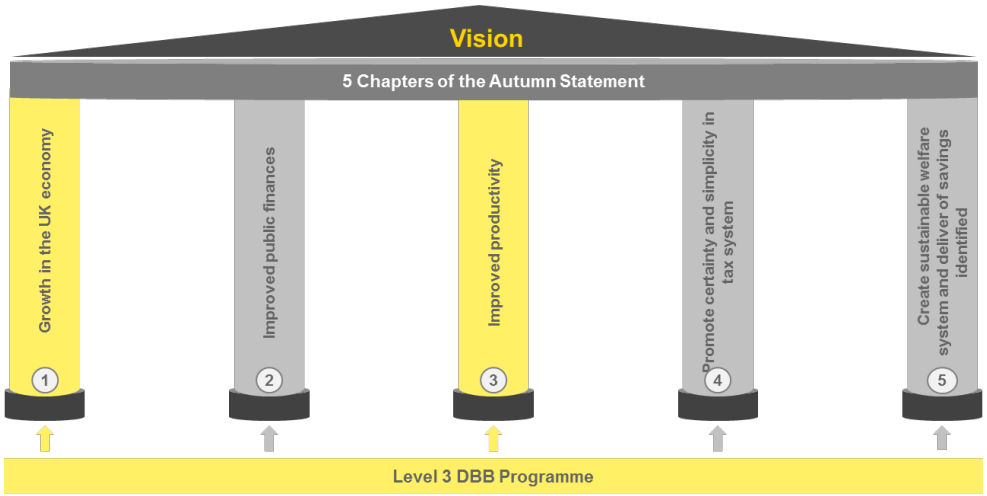


The DBB programme supports the Housing Market Strategy

Groups of Proposals of the Housing Market Strategy	The Contribution of the DBB Programme
Plan for the right homes in the right places	Boosting the ability of local institutions to make strategic house building plans through more accurate supply and demand information
Build homes faster	Better coordinated investment decisions (based on housing needs, utilities planning and delivery, etc.) reduce blockages in the development process

The contribution of the DBB programme to the Housing Market Strategy

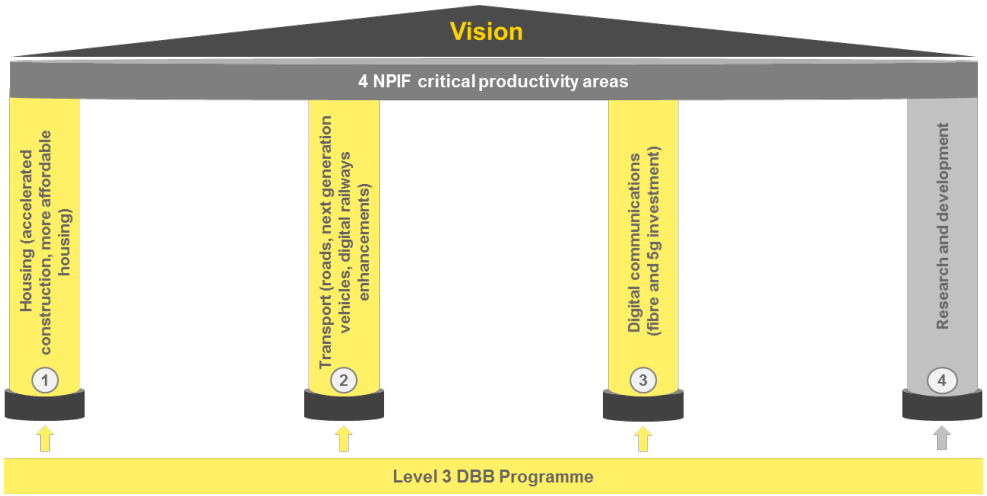
A.5. HM Treasury (HMT): Autumn Statement 2016



The DBB programme enables the Autumn Statement 2016

Chapters of the Autumn Statement 2016	The Contribution of the DBB Programme
Growth in the UK economy (chapter 3)	Increase productivity of construction sector and the improved performance impact of the built environment on socioeconomic factors
Improved productivity (chapter 3)	Through encouraging long-term investment in economic capital and by creating a dynamic economy which ensures resources are put to their best use

A.6. HM Treasury (HMT): National Productivity Investment Fund

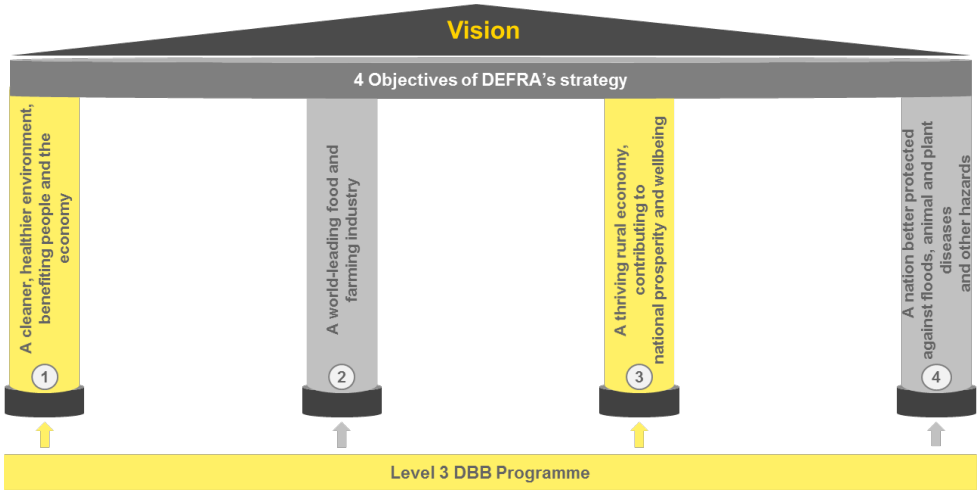


The DBB programme enables the National Productivity Investment Fund.

Critical productivity areas of the NPIF	The Contribution of the DBB Programme
Housing (accelerated construction, more affordable housing)	Better coordinated investment decisions (based on housing needs, transport links, utilities planning and delivery, etc.) and reducing blockages in the development process
Transport (roads, next generation vehicles, digital railways enhancements)	Better data on the utilisation and performance of transport networks
Digital communications (fibre and 5g investment)	Better data on the attributes of the built and natural environment enabling optimal positioning of communications networks

The contribution of the DBB programme to the National Productivity Investment Fund

A.7. Department for Environment, Food & Rural Affairs (DEFRA): Strategy to 2020: Creating a great place for living

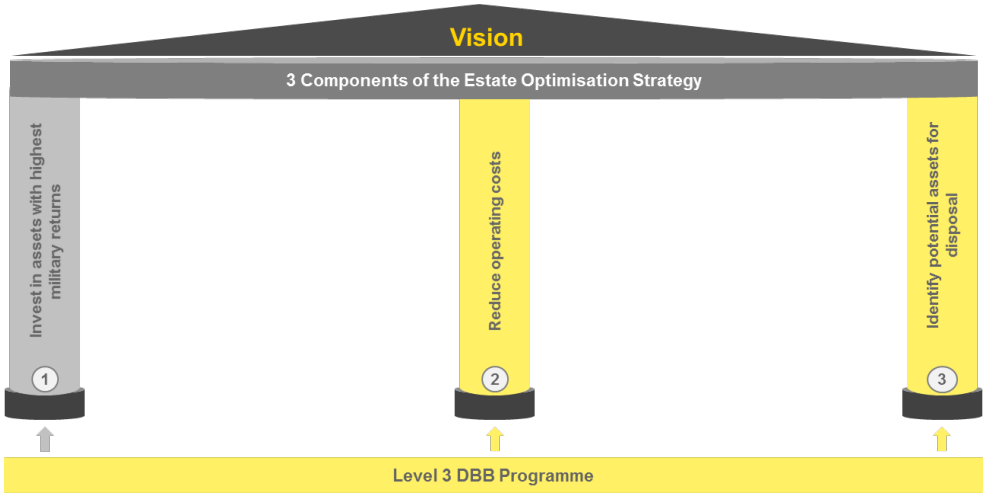


The DBB programme enables DEFRA's Strategy to 2020

Objectives of DEFRA's strategy	The Contribution of the DBB Programme
A cleaner, healthier environment, benefiting people and the economy	Improved data sets on the use of the built environment could allow for cleaner energy use and cleaner transport networks
A thriving rural economy, contributing to national prosperity and wellbeing	Integrated planning (housing, transport, public services) with regional and national transport links

The contribution of the DBB programme to DEFRA's Strategy to 2020

A.8. Ministry of Defence (MoD): Estate Optimisation Strategy

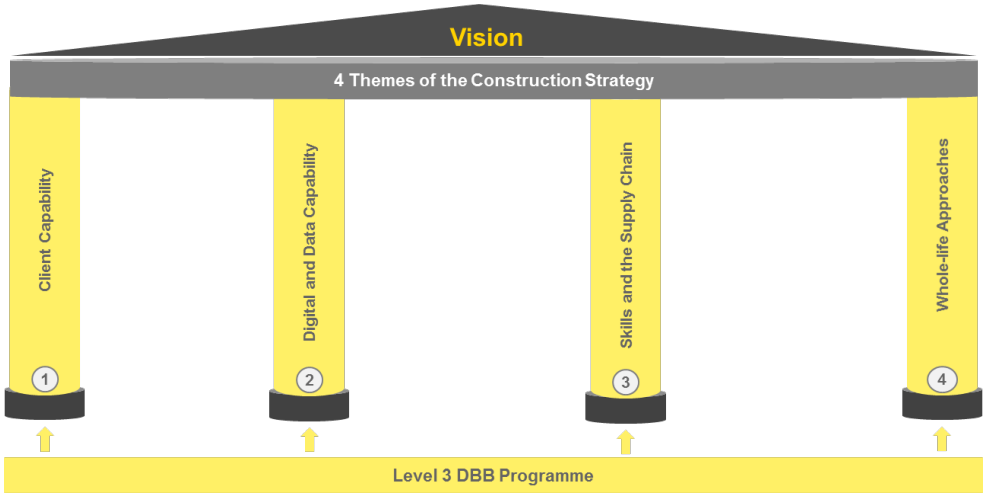


The DBB programme enables the MOD's Estate Optimisation Strategy

Components of the Estate Optimisation Strategy	The Contribution of the DBB Programme
Reduce operating costs	Improved maintenance regime for existing assets through better information
Identify potential assets for disposal	Provides accurate information for more informed and strategic decisions

The contribution of the DBB programme to the Estate Optimisation Strategy

A.9. Cabinet Office and Infrastructure Projects Authority (IPA): Government Construction Strategy 2016 – 2020

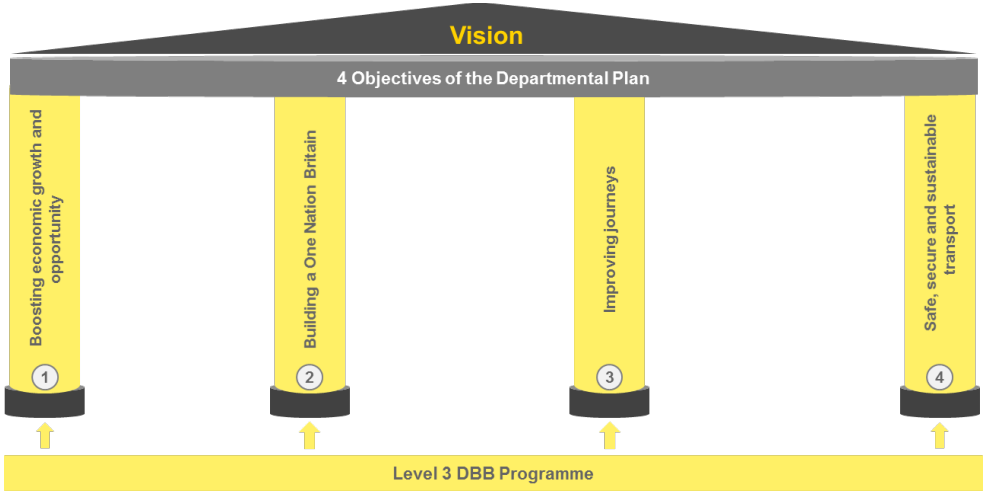


The DBB programme enables the Construction strategy

Themes of the Construction Strategy	The Contribution of the DBB Programme
Client Capability	Develop and embed skills from project delivery, commercial, digital and property functions across central Government
Digital and Data Capability	Using digital technology to increase productivity and efficiencies in construction and operation of assets
Skills and the Supply Chain	Extending information driven decisions through the lifecycle can drive an increase in the number of high skill roles
Whole-life Approaches	A whole-life approach to the management and maintenance of assets can facilitate reductions in cost and carbon footprint

The contribution of the DBB programme to the Construction strategy

A.10. Department for Transport (DfT): Single departmental plan 2015 to 2020

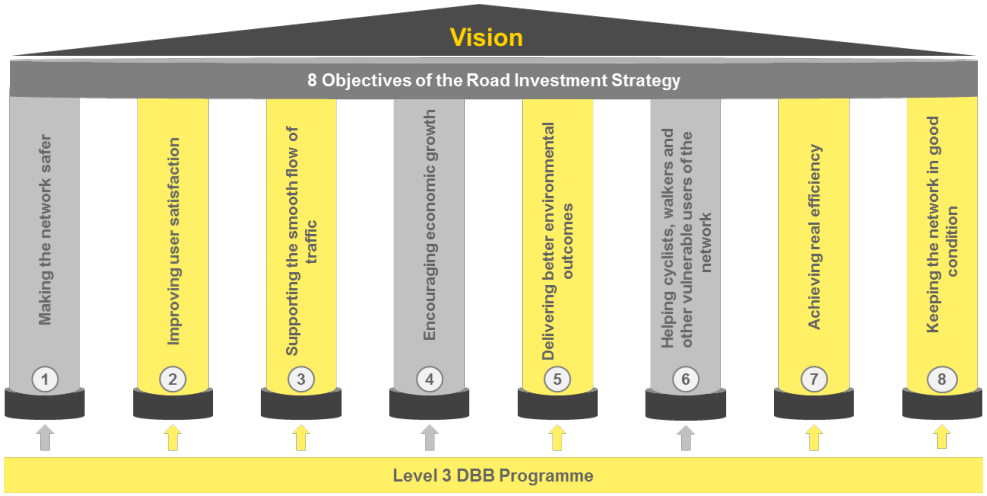


The DBB programme enables the DfT's Departmental Plan

Objectives of the Departmental Plan	The Contribution of the DBB Programme
Boosting economic growth and opportunity	Empower devolved regions to optimise existing built environment and improve strategic investment
Building a One Nation Britain	Ensuring services are delivered at the lowest cost to citizens in urban and regional areas
Improving journeys	Using digital technology to optimise the operation of assets
Safe, secure and sustainable transport	Applying predictive maintenance and ensuring reliability of transport through accurate data

The contribution of the DBB programme to the DfT's Departmental Plan

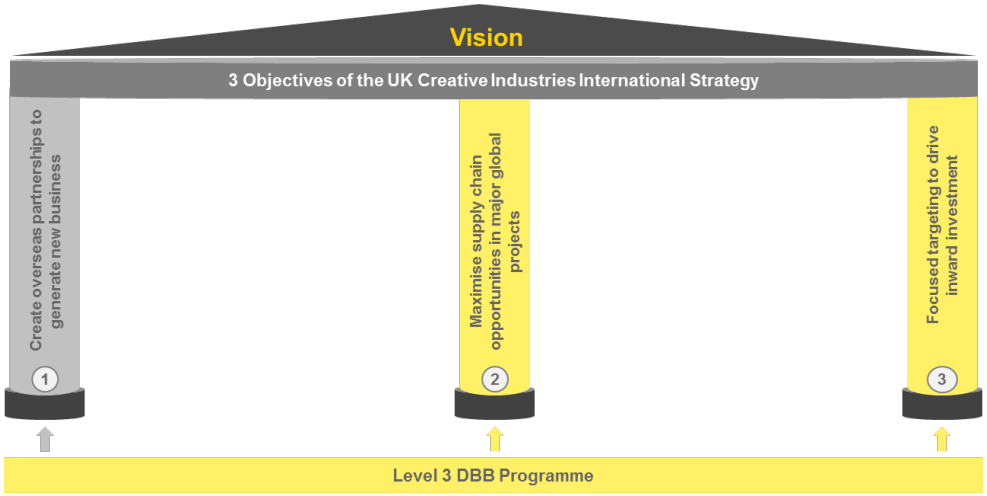
A.11. Department for Transport (DfT): Road Investment Strategy (Highways England)



The DBB programme enables the Road Investment Strategy

Objectives of the Road Investment Strategy	The Contribution of the DBB Programme
Improving user satisfaction	Providing users with dynamic and real-time data to inform their travel decisions
Supporting the smooth flow of traffic	Improving traffic management across strategic roads, enabling predictable journey time on roads and a reduction in planned/unplanned delays
Delivering better environmental outcomes	Reducing environmental impact on the construction and use of roads, through mitigation measures and environmentally positive technologies
Achieving real efficiency	Maximising maximum value for every pound spent, and deliver maintenance faster and cheaper

A.12. Department for International Trade (DIT) (previously UK Trade and Investment): UK Creative Industries International Strategy



The DBB programme enables the UK Creative Industries International Strategy

Objectives of the UK Creative Industries International Strategy	The Contribution of the DBB Programme
Maximise supply chain opportunities in major global projects	Providing a conducive environment powered by digital enablement and innovation to enhance the impact on major overseas projects
Focused targeting to drive inward investment	Supporting inward investment by providing information driven decision making capability to future investors

The contribution of the DBB programme to the UK Creative Industries International Strategy.

B. Impact of constraints in the built environment

	Demographic Pressure	The UK population will rise by 15% to 75 million by 2050[29]. The ageing population is projected to continue to grow to nearly a quarter of the population by 2045[30]. The effect of an ageing population, population growth and urbanisation will put significant strain on the existing built environment and the services it provides. Improved understanding of these demographic changes would make it possible to take these into account during the planning of new infrastructure, as well as the refurbishment of existing.
	Energy Demand	Energy demand could rise by a third to 1200 TWh/year by 2050 depending on the adoption of potentially disruptive new technologies such as energy storage, electric transport and heating. In 2014, there were an estimated 2.38 million households in fuel poverty in England, representing 10.6 per cent of all English households[31]. Greater understanding of existing and future energy supply and demand (both at the macro-economic and micro-economic scale) could provide new insights to optimise energy use to drive growth at a city, regional and national level.
	Transport Efficiency	26% of morning peak trains arriving to London were over-capacity in 2014. In 2013, the average British driver spent 124 hours stuck in gridlock, costing the UK economy £13.1 billion[32]. In 2012, the average speed on London's roads was 19.33 mph, dropping to 8.98 in Central London. In 2016, cars drive at an average of just 16.5 mph, falling to 7.4 mph in the city centre.[33] This impacts productivity and public health as concluded by a King College Study.[34] Overcoming barriers to data sharing could create the ability to better exploit the full potential of the transport network, unlocking up to £14 billion of benefits from new innovations by 2025[35].

	Housing Needs	The UK's housing needs are estimated to amount to at least 300,000 new homes per year for the foreseeable future[36]. The BRE estimates that it costs the NHS c£600 million per annum to treat illnesses caused by living in poor housing conditions in England.[37] The Agile Ageing Alliance reports that the existing housing stock is not able to support the needs of an ageing population. Older adults want housing that will allow them to be independent and self-sufficient, whilst keeping family and friends connected.[38]
	Climate Change	Disruption from flooding costs the UK economy £1 billion per year. Circa 2.44 million properties are at risk of flooding from rivers and the sea, 3 million from surface water flooding, and 244,000 are at high risk of flooding. These numbers are set to increase in future due to population growth and climate change.

C. Development of the Systems Engineering Framework

The approach for developing the Systems Engineering Framework focused on bringing to life the future-state capabilities, future-state commercial services, and future-state technical specification, informed by and complementing the Business Case development.

The approach adopted during the SOBC phase will continue to be developed throughout all future programme phases, with routine reviews undertaken to ensure it remains appropriate, particularly in responses to changes within the programme structure. Development of the Systems Engineering Framework focused on the following key activities:

- aligning with government policy
    - review government policy across departments to align with objectives and outcomes of the Digital Built Britain programme

- identifying target beneficiaries
    - undertake impact analysis of target outcomes to identify beneficiary groups across the economic asset management lifecycle
    - conduct industry interviews and workshops with Client Design Authority to further develop the qualitative benefits profile associated with each beneficiary group

- identifying enabling capabilities and commercial services
    - identify enabling capabilities and commercial services required for the realisation of target benefits and outcomes through the development of the Information Management Landscape

There are some limitations to the System Engineering Framework:

- it does not articulate the delivery transformation roadmap
- the list of capabilities and commercial services is non-exhaustive and limited to those that will be created and developed as part of the Digital Built Britain programme
- it does not provide detail of the “Information Management Landscape” layer, this will be developed at the next programme stage

Going forward, the Systems Engineering Framework will be a key tool to facilitate engagement with and establish advocates amongst key stakeholders of the Digital Built Britain programme. An explanation on each layer of the Systems Engineering Framework is provided in the following sections.

D. Case Studies: Enabling manufacturing approaches

D.1. Anglian Water @one Alliance – Off-site manufacturing

The Anglian Water @one Alliance is a collaborative organisation working to deliver more than half of Anglian Water's (Anglian) capital investment programme. The alliance will design and build around 800 schemes worth approximately £1.2 billion between April 2015 and March 2020. It is responsible for designing and constructing water and water recycling treatment centres that serve more than 6 million people as well as maintaining and improving the water mains and sewage network in the East of England.

The alliance aims to achieve the following goals:

- exceed a 7% reduction in real terms in gross operational carbon by 2020 from a 2015 baseline
- deliver a 60% reduction in capital (embodied) carbon by 2020 from a 2010 baseline
- develop excellent Health and Safety processes
- deliver all projects on time

Anglian has been using a geospatial application which combines a number of data sets including mapping data, environment agency data, western power distribution assets and National Grid data. This application has allowed for better planning prior to construction by, for example, addressing any potential challenges to the successful delivery of the project at a very early stage.

Further, the organisation developed an approach of having "assets as products, not projects". Anglian Water's aim was to design, manufacture and test all of its assets off-site. In order to achieve it, a digital asset catalogue that contains all assets used in water centres was developed. It has information on the use of each asset, operation details, components, associated 3D models and how to integrate them into the network. When planning and designing a new centre, assets can simply be selected from the catalogue according to site specifications. Below are some of the benefits of this approach:

- drive efficiency in regards to time and cost as well as increased quality (reduced margin of error)
- repeatability drives efficiency in production, installation and project delivery
- enables the grouping of projects into batches of products just like a factory delivery line

For example, this approach was used for Sampling Kiosks – a facility from which samples are taken from reservoirs for pollutant testing – that are now produced offsite. Anglian was able to produce 11% carbon savings and 23% cost savings as compared to the kiosks made in the past. Installation time on site has also been reduced by 50%.

D.2. Off-Site Manufacturing

A study by the charity Waste and Resource Action Programme (WRAP) found that, versus a traditional brick and block system, off-site manufacturing lead to a 27% reduction in labour required for house construction, a figure broadly in line with other findings indicating increased site productivity.

Additional benefits of off-site manufacturing include shorter construction times, reduced waste and safer working conditions. Off-site construction currently contributes between £1.75 billion to £4 billion per year to the construction industry.

E. Case Studies – Operational Effectiveness

E.1. Network Rail – ORBIS and Digital Railway Programme

ORBIS – Information-enabled infrastructure maintenance decision making

The Offering Rail Better Information Services (ORBIS) programme has implemented new business processes and capability to bring about significant and sustainable improvements in the cost of managing, maintaining and renewing Network Rail's £46 billion asset base, whilst improving safety and asset reliability across the UK rail network. This programme has enabled the rail network to meet the challenge of delivering increased passenger and freight capacity, whilst creating value for the UK taxpayer.

The programme overhauled the processes and systems used to collect, join and analyse data, enabling Network Rail to move from a time-based plan-preventative asset management approach to a predict-and-prevent approach, informed by good quality information. Capability provided included iPads, iPhones and associated applications to enable maintenance staff to capture asset data in the field, instrumented trains to automate data capture of linear datasets, and decision support tools to enable better informed decisions about whether to renew or replace asset.

By exploiting more accurate data, Network Rail was able to eliminate £100 million per year from its asset management activity, and improve asset reliability to its historically best-ever level, with, for example, broken rail incidents dropping from over 350 per year in 2012 to zero by 2016. While ORBIS' primary goal was application of information to improve asset management effectiveness, a similar predictive analysis and optimisation approach could be taken to address energy efficiency or managing any other asset system or network of systems.

These outcomes depend on the combined analysis of spatial, asset system and operational data. Network Rail's information systems have been built in proprietary information formats, making it difficult to apply to other, similar, challenges in other linear asset infrastructure systems such as roads or utility networks. The work of Digital Built Britain would enable significant reuse of investments like this one across the government estate in future.

Digital Railway – Command and Control System

Digital Railway is a rail industry-wide programme designed to benefit Britain's economy by accelerating the digital-enablement of the railway. This acceleration will unlock capacity from our existing infrastructure to enable more trains, better connections and greater reliability across our existing network.

One further benefit of the programme will be the reduction in energy consumption through digital signalling. Currently, traffic is controlled through a mix of systems, mainly by a "fixed block safety control system" operated through physical signals, working pretty much like traffic lights at the entry point to each block section of railway. However, a move towards a digital command and control system would enable train speeds to be automatically and optimally regulated and the flow of trains to be choreographed to hit all the lights on 'green'. The elimination of start-stop reduces equivalent energy consumption by 15%. The Victoria, Jubilee and Northern Lines have installed new Automatic Train Operation (ATO) systems and have seen energy consumption reduced by up to 30%.

E.2. Anglian Water @one Alliance – Smart metering and sensors

Though the UK has been a slow adopter of smart metering and sensors in the water industry, Anglian has installed sensors all across the physical water journey. These enable monitoring procedures such as using data to create risk maps of where there are decreases to water pressure in the network.

By doing this, Anglian is able to better predict the amount of water that is required to be pumped into the system and, when and at what times less water pressure is required. Such procedures allow for water and cost savings.

By applying this principle Anglian has begun to reduce water pressure at times of the day when people tend to use less water, i.e. the demand is lower and therefore supply is decreased. Sensors can also provide live data on leakages which enables continued maintenance and rapid fixing in case of an incident.

Furthermore, Anglian is gamifying water usage through their smart meters. Using an app, people can track what their water is being used for, how much they are using, how much it is costing, and are incentivising customers to save through rewards and competing against friends or neighbours.

E.3. Operate for less: Case study – Microsoft 'Smart Buildings' Programme

As part of Microsoft's efforts on environmental sustainability, the firm is addressing energy consumption and carbon-footprint reduction by building energy efficient data centres. Microsoft is investing in the deployment of new technologies to improve performance, reduce operational expense and cut emission footprint. With the help of smart building solutions and collection of real-time usage data, engineers can optimise building base load, the power consumed by the major building systems, such as HVAC or lighting.

Supported by analytics, they can tune set points and schedules, isolate wasteful equipment and address other opportunities by getting a much better understanding of energy use and trends across the building portfolio.

Benefits:

- kilowatt-hours consumed per employee as a performance indicator can be benchmarked across organisational units and observed over time
- energy costs can be accurately broken down by organisational unit to define ownership and create incentives for managers to save energy

By making real-time data available across sectors, the DBB programme will allow facility managers to gain a greater understanding of the energy consumption and carbon-footprint of their own asset as well as highlighting opportunities of reducing energy use across asset systems.

E.4. NHS Estates and Facilities

During a merger between two NHS providers, it became apparent that one provider's energy costs were much higher than the other. Further investigation revealed that this was down to the excessive use of oil due to the age and condition of the boiler, yet the variation did not become apparent until it was identified through comparative benchmarking during the merger process.

Year-on-year budget setting had topped up the estates budget to meet the rising costs of the demand for oil. This demonstrates the need for metrics to enable hospitals to recognise when and where costs have become unusually high, encouraging estates managers to take action to reduce costs.

E.5. GE Power – The "digital power plant", the first step towards making the internet of energy a possibility

GE Power, whose turbines generate 30% of the world's electricity, have been working on applying Big Data, Internet of Things and machine learning to build an "internet of power". GE's Chief Digital Officer emphasised that the company is moving towards "a world where every electron will have a data bit associated with it". Data feeds directly into GE's asset performance management software enabling predictive maintenance and power optimisation and thus, unlocking value through the use of rich data. GE has seen results of unplanned downtime by 5%, reducing false positives by 75%, reducing operations and maintenance costs by 25%.

E.6. Green Deal

The potential economic benefits of widespread uptake of the Green Deal are significant. For example, this could generate large savings on domestic energy bills. The Energy Saving Trust calculates that loft insulation of 270mm could save the average 3-bedroom house up to £180 per year on its energy bill, and double glazing could save around £170 per year.

If 20 per cent of the UK's approximately 25 million households were able to achieve these combined savings of £350 per year, this would equate to an annual saving on domestic energy bills of £1.75 billion. In addition, and more directly relevant to the current focus of Honest Buildings, there is also the potential for savings on the energy bills of commercial properties. The scale of the potential savings is more difficult to estimate as there exists no comprehensive register of the UK's commercial property stock. In addition, commercial buildings are more heterogeneous in nature, meaning that it is more complex to assess the benefits of energy saving measures.

As an indication, the 2010 DECC impact assessment for the Green Deal calculated potential energy savings of between £170 million and £330 million, based on an additional uptake of energy saving measures of 10 to 20 per cent above a business-as-usual scenario. However, these savings are set against capital costs of between £75 million and £140 million.

F. Case Studies - Optimise capacity

F.1. Smart Motorways

Smart motorways use traffic management methods to increase capacity and reduce congestion in specific areas of the road network that can become particularly busy. These methods include using the hard shoulder as a running lane and using variable speed limits to control the flow of traffic.

Highways England developed smart motorways to manage traffic in a way that minimises environmental impact, cost and time. The smart motorways control systems require spatial, road system and operational performance data in order to operate efficiently. This data is proprietary and owned by a third-party supplier who operates the system for Highways England.

In 2007 it was estimated that smart motorways could be introduced within 2 years at a cost of around £5-15 million per mile as opposed to 10 years and £79 million per mile for widening. The M42 scheme was initially run as an experiment and a Highways Agency report into the first 6 months of the scheme showed a reduction in variability of journey times of up to 27%.

Highways Agency also indicated a fall in the number of accidents from over 5 a month to 1.5 per month on average. The Agency did state that normally accident statistics should be compared over a 3-year period, so the initial results should be treated with caution. They also stated that no accidents had been caused by using the hard shoulder as a normal lane.

The report also stated that there had been a 10% fall in pollution and 4% fall in fuel consumption. The report also indicated a compliance rate of 98% to the indicated speed limits when using the hard shoulder. For comparison before the introduction of mandatory speed limits at road works, the compliance rate was 10% as opposed to 89% afterwards, showing a similar effect.

A report by Arcadis (2016) indicates that Smart Motorways increase road capacity by 33% and avoid the considerable environmental impact of constructing new roads. Their analysis of data from the smart motorway schemes highlights that, though the motorways now carry more traffic, there has been no significant increase in consequent noise or air pollution. This can be attributed to the reduction in speed and smoother flow of traffic resulting in lower emissions.

F.2. Digital Railway Programme – Network Rail

The railway is a fundamental component of UK infrastructure, connecting people with jobs and manufacturers with markets. 1.6 billion journeys are taken annually, and one quarter of all container freight is shipped by rail. Since privatisation in 1994 the railway has seen steady growth, with passenger numbers doubling over the last 20 years.

The rail industry traditionally responds to increased demand by re-signalling, building new tracks and extending train and platform lengths. These conventional methods of increasing capacity are expensive, disruptive and slow.

The UK is now embarking on a programme of digital modernisation of train control by installing digital command-and-control systems. These systems remove the need for line-side signals and enable trains to safely run closer together, releasing latent capacity by up to 40%, and eliminating 35% in primary delays caused by conventional signalling asset failures.

Network Rail's Digital Railway programme is building business cases for modernisation of the most overcrowded and congested routes through the analysis of spatial, system and operational data to determine where the greatest improvements in capacity can be achieved. This modelling is being carried out using proprietary infrastructure data sets established by the ORBIS programme at a cost of c.£100 million, datasets describing passenger and freight demand and operational datasets describing the performance characteristics of different types of trains.

Whilst the benefits of the Digital Railway programme's outcomes are clear, the scope of the investigation is limited to analysis of the rail network. Interoperable data and analysis tooling, enabled by the DBB programme, could be applied cross-sector to transport capability to include, for example, the national rail network, the strategic road network and local authority road networks within the same overall model.

Joined-up infrastructure planning could then identify the optimum road/rail interchange points and resultant train service patterns to optimise the overall connectivity between where people live and the cities in which they work. This would improve overall productivity, optimise new transport investments, reduce

traffic pressure on city-centre infrastructure, reduce carbon emissions and improve air quality.

F.3. Connected Boulevard, Nice, France

Boulevard Victor Hugo in the centre of Nice contains almost 200 different sensors and detecting devices. In addition to these, the Boulevard plays host to "guest" devices such as mobile phones and tablets used in the streets that are connected onto its wireless mesh network.

Data captured through these "devices" is processed and analysed to offer the city and its residents invaluable context-aware information on parking, traffic, street lighting, waste disposal, as well as environmental quality as experienced in real time. After the initial installation of Connected Boulevard in Nice, traffic congestion was reduced by 30 percent and air pollution was reduced by 25 percent.

F.4. Heathrow – Optimisation in aviation, a success story

Aviation is key to an effective transport sector. Over the last few decades, the aviation industry has had to respond to a surge in demand with the introduction of passenger and freight aviation. Heathrow airport (London, UK) is one example where airport capacity can quickly became an issue.

During the 1960s a new runway was built in response increasing demand, and the existing runway extended to increase the quantity and size of aircraft permissible at Heathrow. However, towards the end of the 70s this additional capacity had been exhausted. This raised the prospect of building a third runway.

Heathrow went through a period of digital modernisation during the 1980s that included setting up the National Air Traffic Services, new Instrument Landing Systems, a modernised Control Room Approach, mandatory use of Autopilot system and the installation of new Navigation Beacons. The information models underpinning this modernisation included proprietary spatial, system and operational aviation datasets as the critical enablers.

This digital air traffic management released over 60% of additional capacity, allowing for a significant increase in throughput on both runways, mitigating the need for the additional runway to be built. A plane can now land or take off every 45 seconds at Heathrow.

G. Case Studies - Connecting people with employment

G.1. Milton Keynes, Oxford, Cambridge Corridor

In December 2014, Transport Secretary Patrick McLoughlin and Chief Secretary to the Treasury Danny Alexander announced an ambitious £15 billion plan to triple levels of spending by the end of the decade, in order to increase the capacity and condition of England's roads. Furthermore, Philip Hammond pledged £110 million funding for the Bicester-Bedford segment of the east-west rail link as part of the Autumn Statement 2016, aimed at ensuring its completion by 2025.

The strategic planning approach across the corridor could help to unlock significant economic dividends, not just for the corridor but for the UK as a whole.

Currently the region is suffering from an undersupplied housing market and poor east-west transport connectivity. Between 2012 and 2015, 3,700 fewer homes than required were built. The National Infrastructure Commission (NIC) expects to see the number of jobs across the corridor increase to 335,000 by 2050, cumulating in an increase of economic output by some £85 billion. When housing needs are better met and the east-west links succeed in bringing distinct sub-regional economies closer together, the NIC expects a further 700,000 jobs to be created by 2050, increasing Gross Value Added (GVA) by £163 billion.

The challenge:

The corridor cuts across the UK's "economic heartland" including 17 district councils, 5 unitary authorities and 5 county councils. The programme sets out to develop a strategic plan for transformative, large-scale developments that integrates new homes, jobs and infrastructure. The ambitious initiative not only bridges regional divides, but acts across sectors and aims to implement more than 15 individual schemes (road, rail, housing, employment, etc.).

Each of the councils and authorities hold sovereignty over developments within their own areas. When it comes to collaborative decision processes and development structures, 27 separate governance processes need to be considered. Additionally, crucial information exchange and modelling is prohibited by a lack of quality and trust of the shared data. This directly affects the programme's transformational potential and, in all likelihood, its ability to deliver significant housing and infrastructure development regionally.

Considering the primary east-west road route of the corridor, there is a forecasted increase of 32-40% of trips by 2035. Without investment in new strategic infrastructure this will result in substantial increase in congestion, journey time delay and journey time variability. According to the Department for Transport, if left unchecked the congestion and unreliability of journeys could waste an extra £22 billion worth of time, and add an extra £10 billion in annual costs to business, by this time.

The Digital Built Britain programme will enable integrated planning across multiple sectors, asset systems and geographies such as local authorities, cities and the regions involved in this programme.

In order to accelerate the unlocking of the expected benefits from the Cambridge – Milton Keynes – Oxford corridor, a new way to facilitate collaboration and commitment at all stakeholder levels will be necessary. Data modelling and transfer play a key role in this exchange and it will require a fundamental shift in the scale at which local authorities collaborate on planning and infrastructure data. The Digital Built Britain programme will ensure the delivery of common, unambiguous, interoperable, scalable and trusted information across sectors and geographies, allowing clearer communication and quicker agreements that unlock benefits faster.

Capability information: The Digital Built Britain solution enables multiple stakeholders to share capability information of their asset systems. The ability to understand the current and potential functional capabilities of the asset networks will permit a better understanding of future risks and opportunities allowing more efficient planning. Better traffic management capability will lessen the impact of traffic congestion across the network reducing network disruption and improving reliability.

G.2. Devolution – The Shift Of Power From Westminster To The Regions

As the devolution agenda shifts power and funds from Westminster to the UK's Regions, it is increasingly the responsibility of elected mayors and regional bodies to improve connections between people and employment, and between manufacturers and markets. In Birmingham, the first mayoral election will take place in 2017. In addition to enhanced powers to raise and borrow funds, the elected mayor will be responsible for:

- a consolidated, multi-year transport budget
- franchised bus services, railway stations, and 'smart ticketing' in Greater Manchester
- a Housing Investment Fund of £300 million over 10 years, making loans to house builders (and thus being self-sustaining over time)
- planning the integration of health and social care

Regional bodies also have an interest in regional development. As part of the Midlands Engine Strategy, Local Enterprise Partnerships across the Midlands have been provided with £392 million to invest over the next 4 years, including £151 million for the West Midlands City Region.

Meanwhile, the Midlands Connect Partnership aims to boost economic growth, create jobs and lower business costs in the region through reductions to journey times for road and rail users. Elected mayors and regional bodies require the capabilities to make joined-up strategic investment decisions that consider transport, housing, health and other local issues together.

By providing the necessary information to model the economic impacts of strategic investment decisions, Digital Built Britain will support local/regional authorities in their strategic investment planning and decision making.

G.3. Highways England

The UK is ranked the 4th most congested developed country in the world. In 2013, the average British driver spent 124 hours stuck in gridlock, costing the UK economy £13.1b billion The annual cost is set to rise by 63% to £21.4 billion by 2030. Increasing congestion can be observed in London, where the average speed on the road decreased by 14.6% (from 19.33 mph to 16.5 mph) between 2012 and 2016. This has both a direct and indirect economic impact on car-dependent commuters. Direct costs relate to the value of fuel and the time wasted rather than being productive at work, and indirect costs relate to higher freighting and business fees from company vehicles idling in traffic, which are passed on as additional costs to household bills.

Optimisation of our road network is therefore both an urgent need and a high priority. Highways England has a CP5 investment budget of £17 billion to operate, maintain and modernise England's roads. The agency contracts multiple suppliers for the delivery of enhancement and maintenance programmes, and each supplier captures different data sets, uses different systems, and works with different data models. Highways England is required by the Office of Rail and Road (ORR) to submit evidence-based strategic business plans in order to secure investment for each new control period – and this requires data from across the road network.

Highways England is unable to use the data obtained by suppliers for a number of reasons, for example:

- disparate, incompatible information systems – different contractors use different systems
- lack of trust in data – multiple data sources, without common asset information specification
- lack of re-usability – asset information is inconsistent and not usable with varying standards and details
- manual consolidation required – updating asset information is difficult if maintained in multiple systems

As such, the agency has to manually re-survey its physical assets in order to obtain the data required to support its strategic business plans and meet ORR regulations, representing a significant productivity loss as workers spend time re-collecting data.

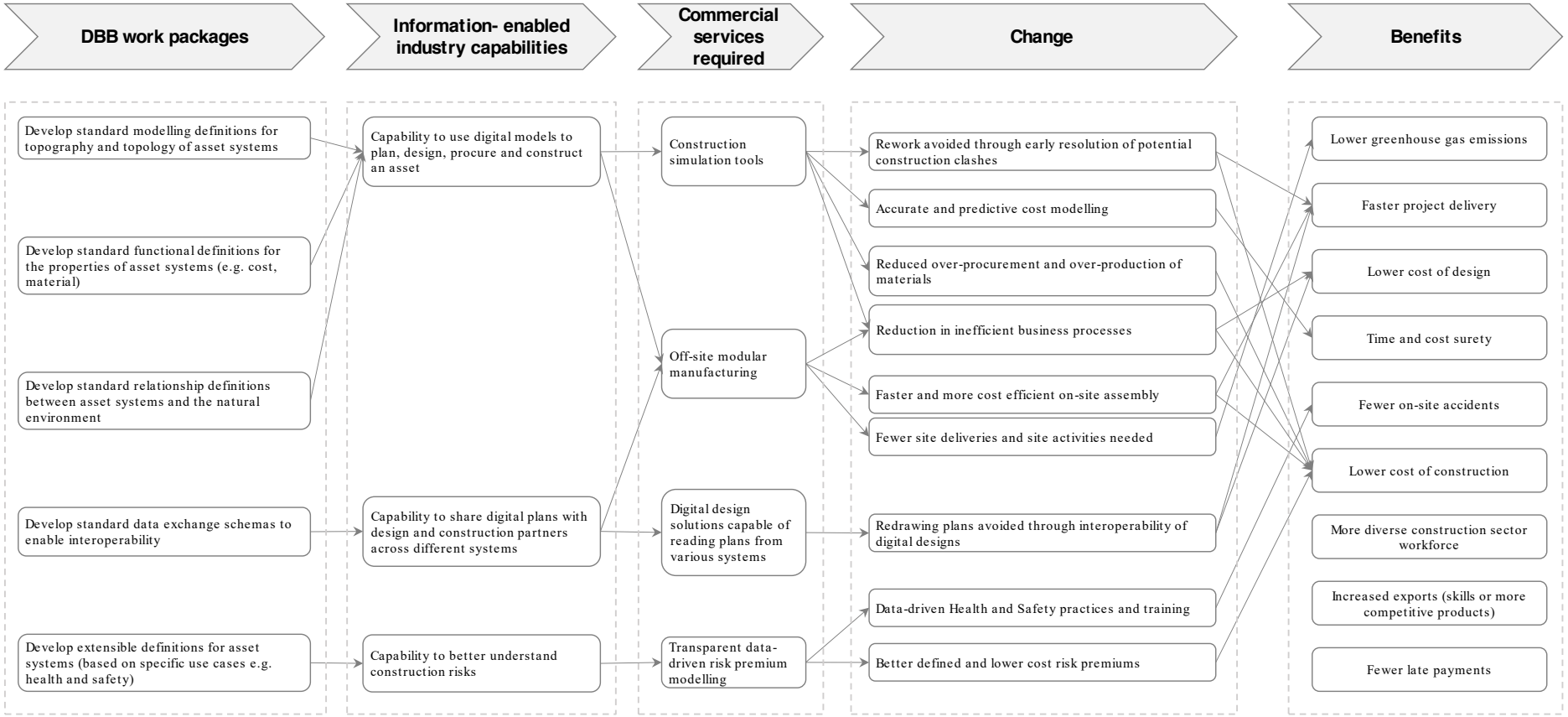
Evidence suggests the agency faces difficulties in obtaining evidence to support its strategic road investment decisions; the National Audit Office (NAO) has called for the agency to review its Road Investment Strategy, stating that a number of projects do not have clear evidence that they represent value for money.

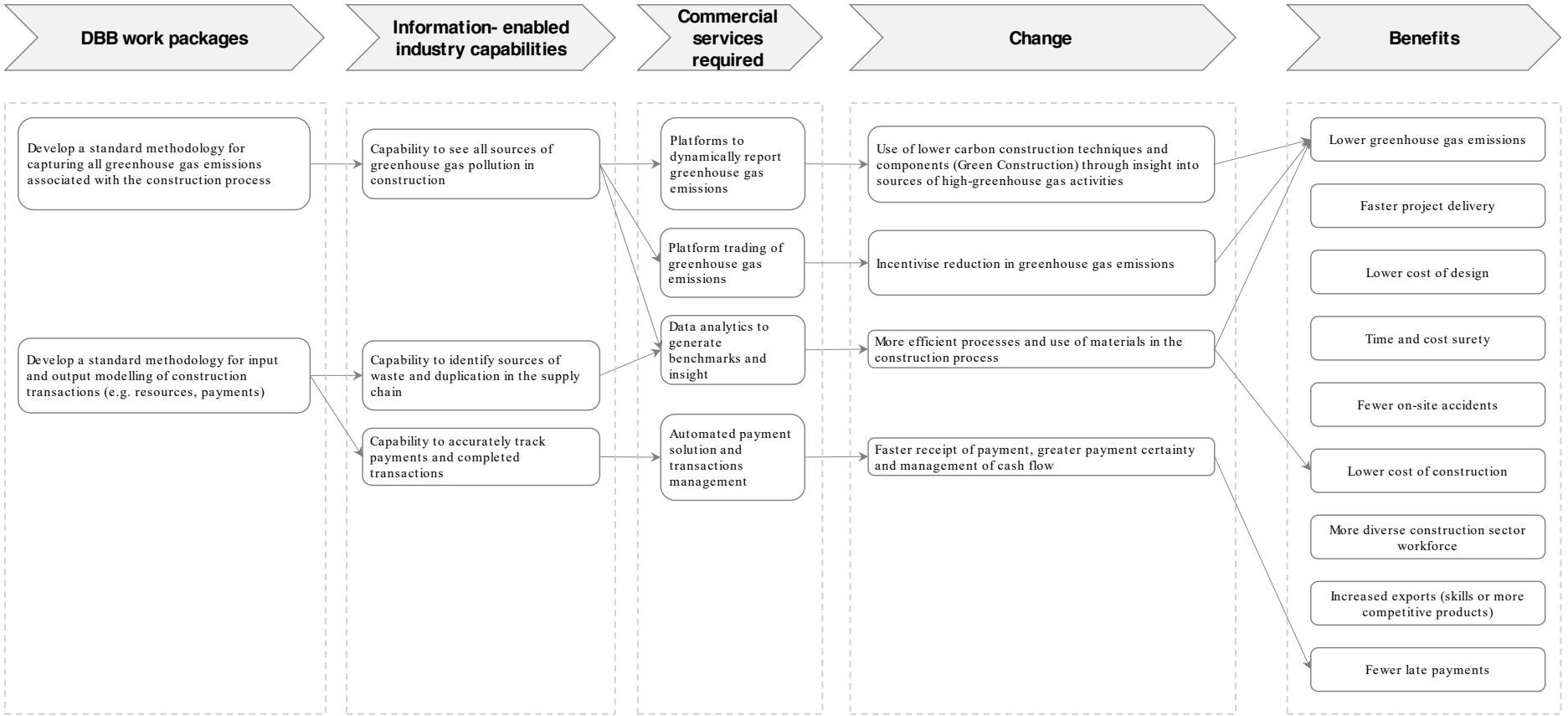
There is a wider missed opportunity relating to Highways England's strategic road investment decisions. This is due to the fact that decisions on investment to optimise the road network are currently made in the absence of a sector-wide capability model (including, for example, the capability of national and local roads, buses, rail and tramways). In practice, this would mean having an understanding of the following issues, which the DBB programme could enable:

- current demand across the transport network, what are the pain points, and when and where is the road network under-used
- how road traffic patterns be optimised
- how data from local authorities, social services, energy systems, other transport networks can be developed into an integrated network model to inform optimised decision-making
- how future demands are likely to develop

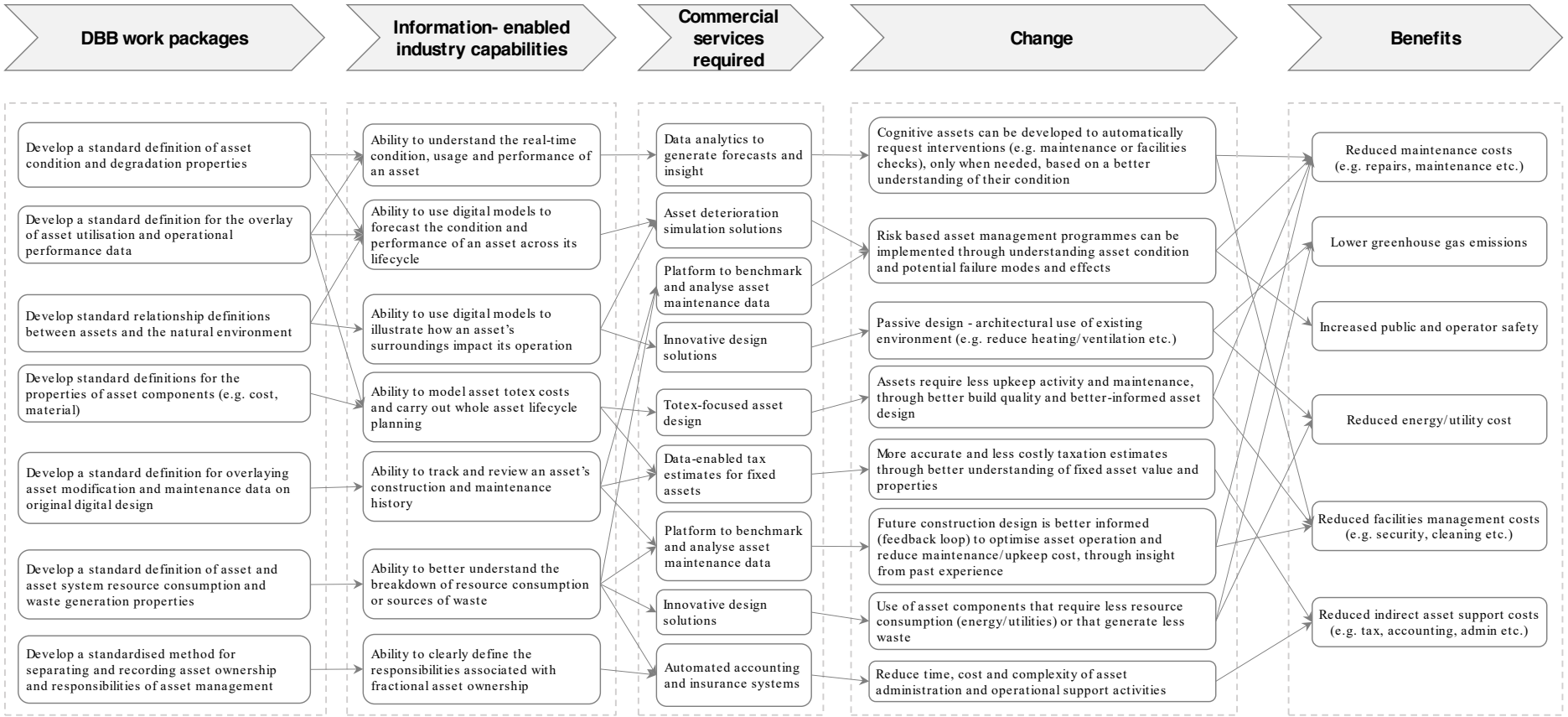
H. Approach to benefits development

H.1. Benefits Logic Map – CapEx



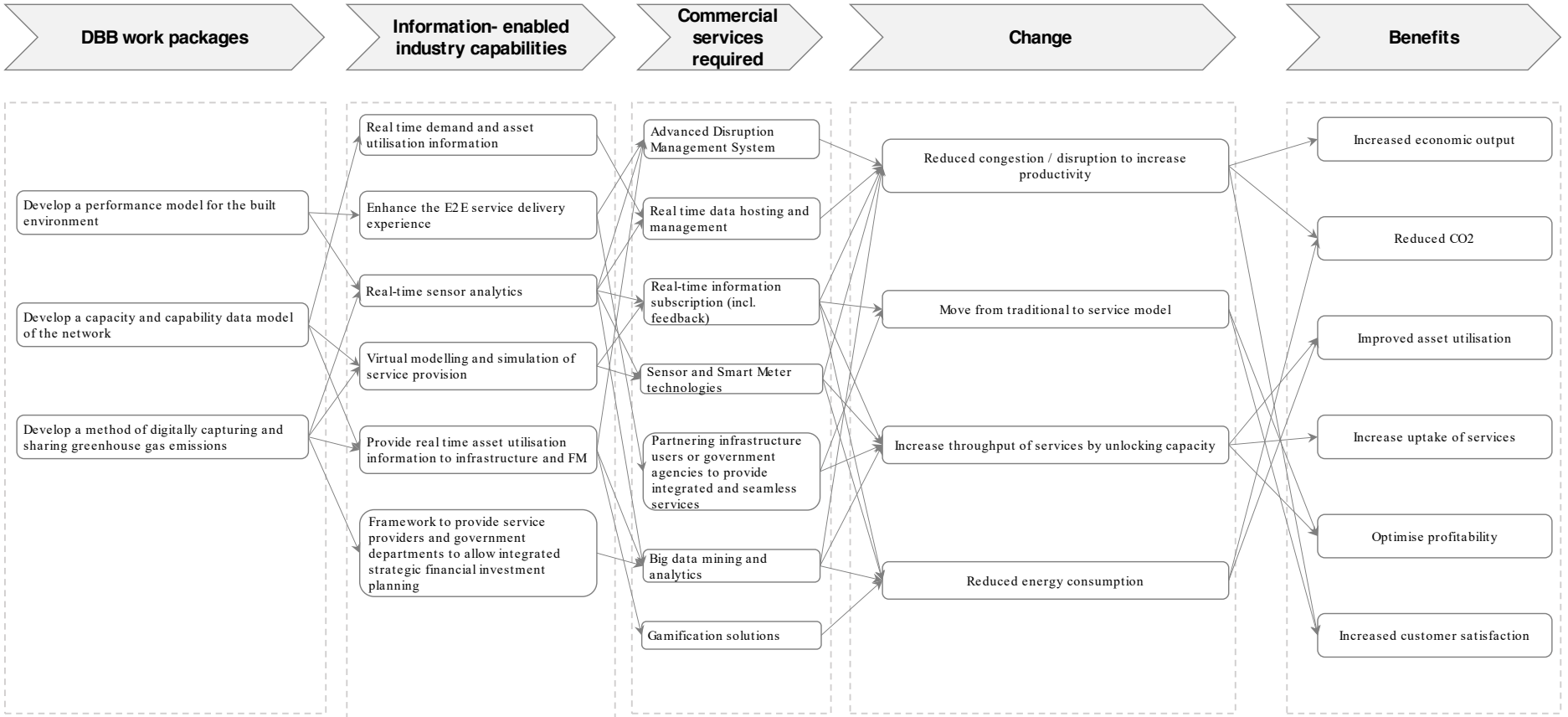

DBB work packages
Information- enabled industry capabilities
Commercial services required
Change
Benefits
Develop a standard methodology for capturing all greenhouse gas emissions associated with the construction process
Develop a standard methodology for input and output modelling of construction transactions (e.g. resources, payments)
Capability to see all sources of greenhouse gas pollution in construction
Capability to identify sources of waste and duplication in the supply chain
Capability to accurately track payments and completed transactions
Platforms to dynamically report greenhouse gas emissions
Platform trading of greenhouse gas emissions
Data analytics to generate benchmarks and insight
Automated payment solution and transactions management
Use of lower carbon construction techniques and components (Green Construction) through insight into sources of high-greenhouse gas activities
Incentivise reduction in greenhouse gas emissions
More efficient processes and use of materials in the construction process
Faster receipt of payment, greater payment certainty and management of cash flow
Lower greenhouse gas emissions
Faster project delivery
Lower cost of design
Time and cost surety
Fewer on-site accidents
Lower cost of construction
More diverse construction sector workforce
Increased exports (skills or more competitive products)
Fewer late payments

H.2. Benefits Logic Map – OpEx

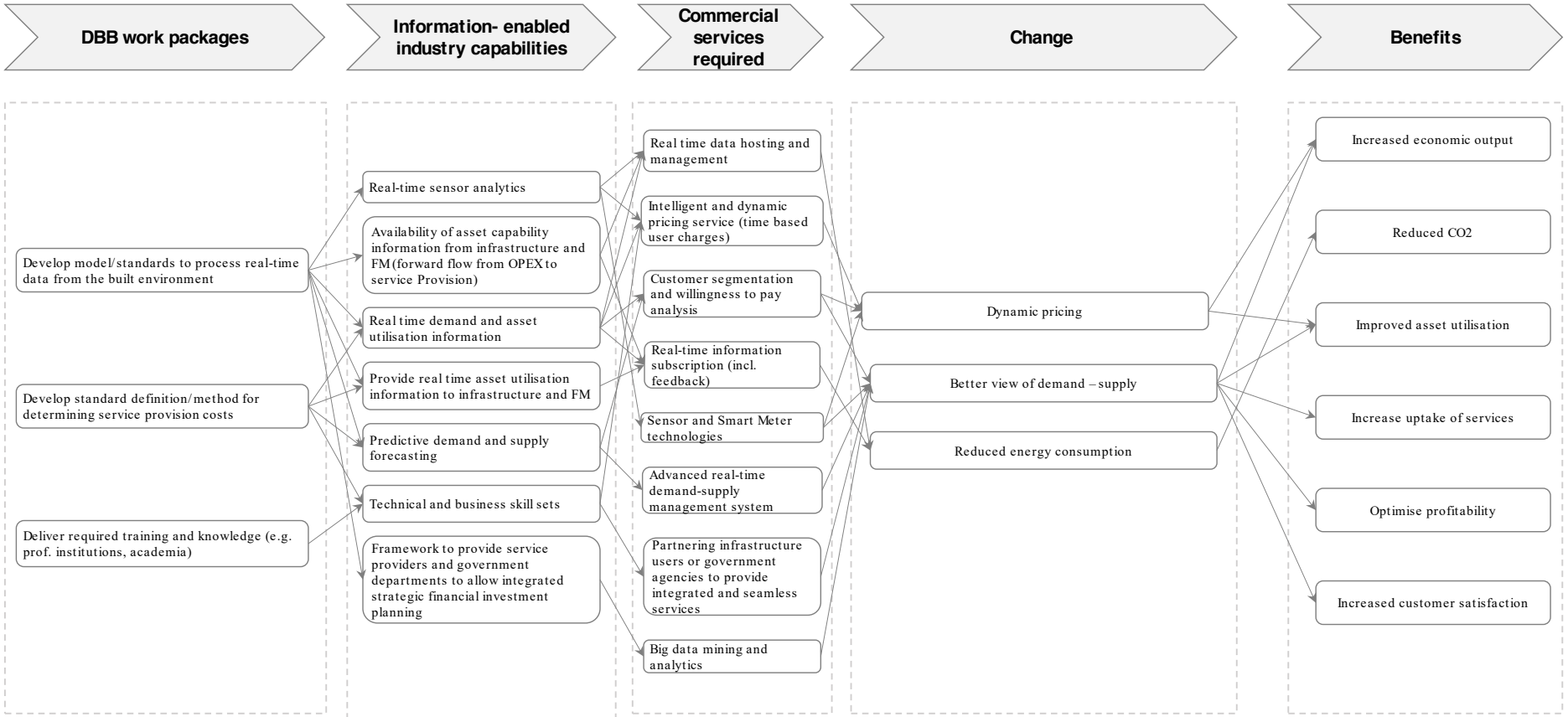


H.3. Benefits Logic Map – Service Provision

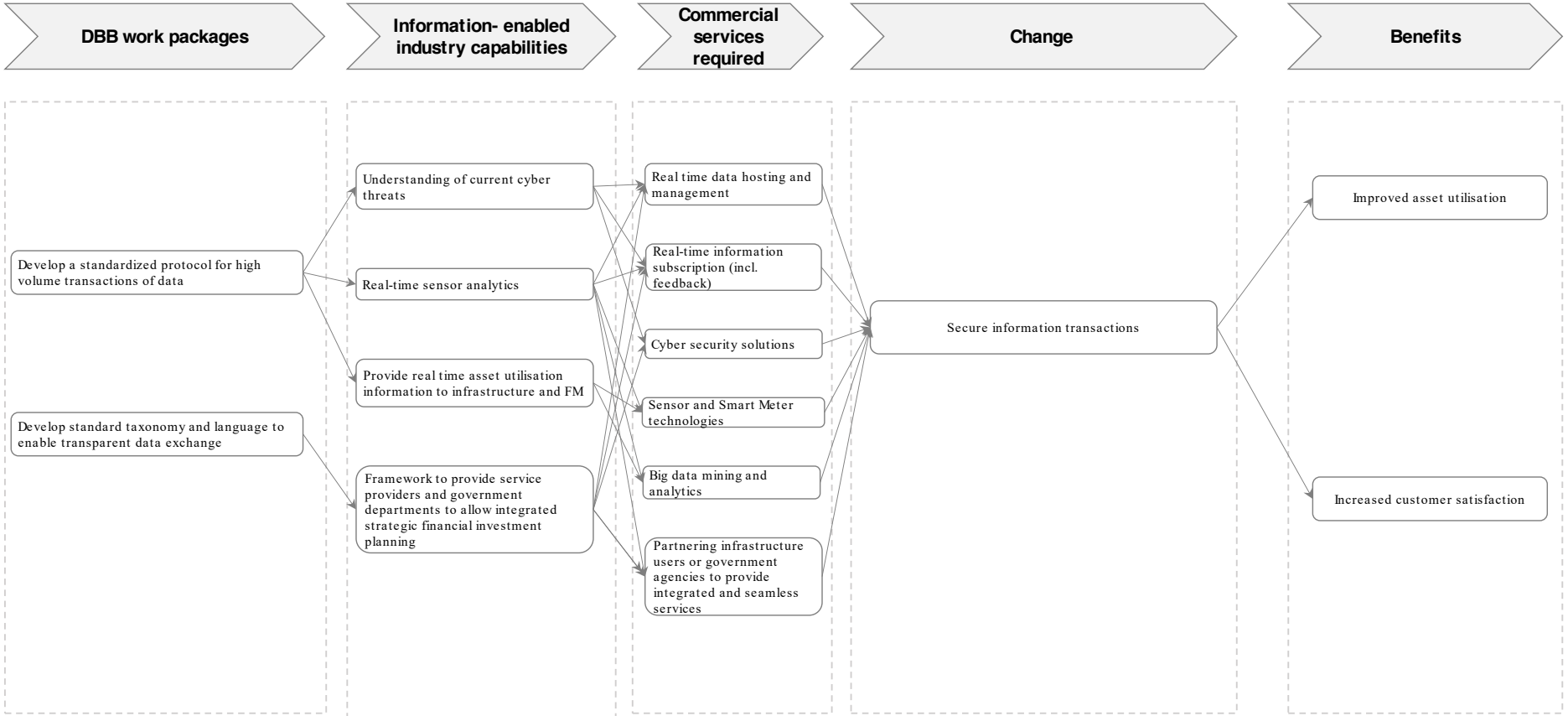
Focus area: Real-time data on the built environment



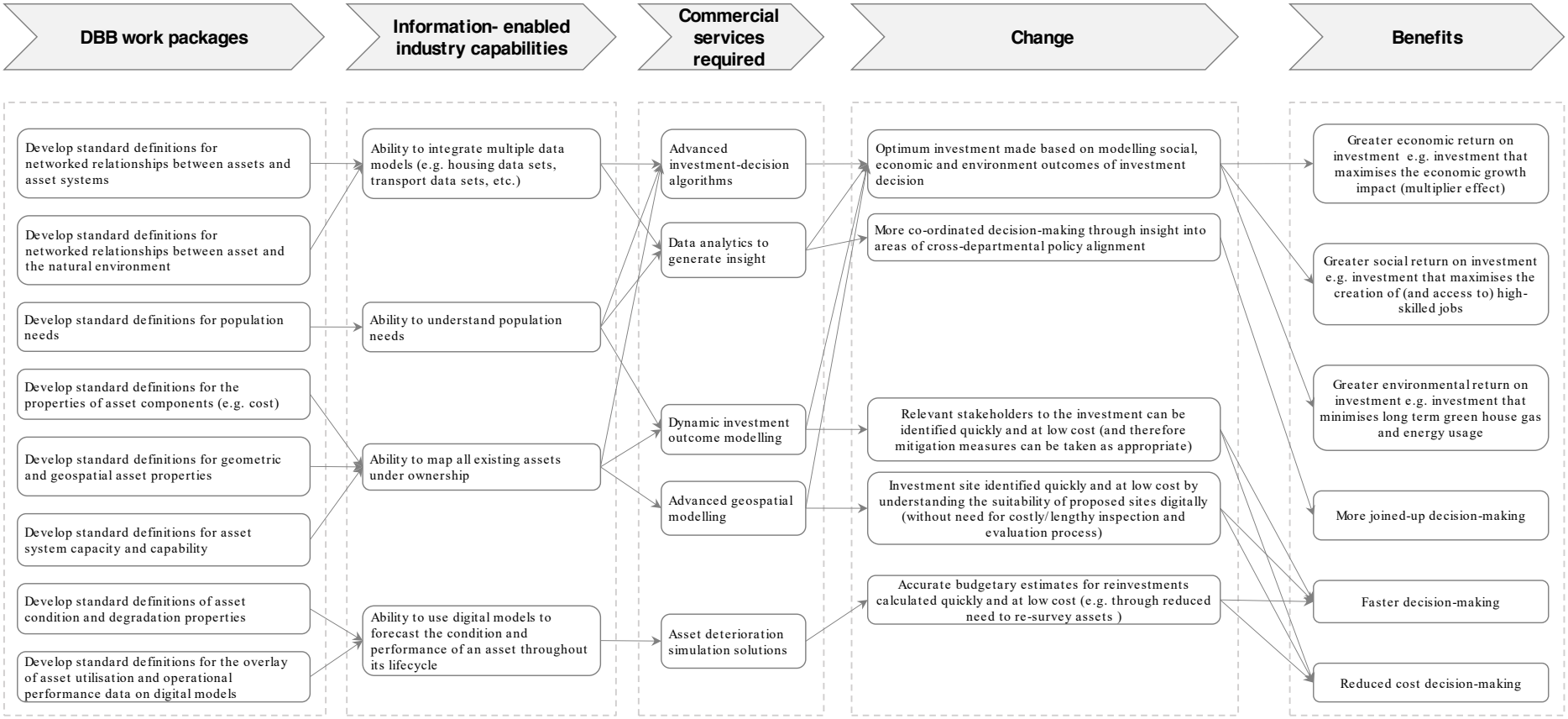
Focus area: Dynamic capability to manage supply / demand



Focus area: Capturing and processing high volumes of real-time data



H.4. Benefits Logic Map – Strategic Financial Investment Planning



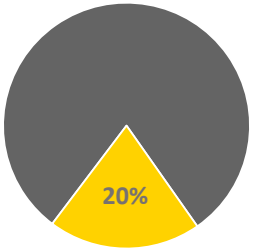
H.5. Benefits Calculation Approach

Determine the annual value of the benefit area

I.e. we have determined that energy/utility cost is…

Determine the annual % benefit that can be influenced through the DBB programme

It has been estimated that the DBB programme will reduce energy/utility cost by…*



This will be achieved through innovative design solutions that will lead to:

- *Passive design; architectural use of existing environment*
- *Use of asset components that require less resource consumption (energy/utilities) or that generate less waste*

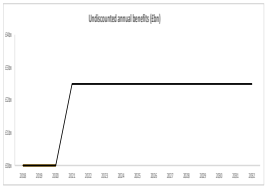
Calculate annual benefit (£)

It has been estimated that energy/utility cost will be reduced by…*

£1.3bn

Profile the benefits over a 15 year period

Assumed no benefits will be achieved in the first 3 years and the full per annum benefit will be achieved in 10 years time



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