UNIVERSITY OF CAMBRIDGE
Centre for Digital Built Britain

Digital Built Britain - *R&D Work Stream*

A study for the Future Cities Catapult

Centre for Smart Infrastructure and Construction (CSIC) and IfM Education and Consulting Services
University of Cambridge

Summary of Research Report

The Value Proposition

The digital age brings unprecedented opportunity and this opportunity requires collaborative action. The UK has the potential to lead one of the defining developments of the 21st century, which will enable the country to capture not only all the inherent value in our built assets, but also the data to create a digital and smart city economy to transform the lives of all: Digital Built Britain's scope has been extended beyond construction to include information to support current and future cities.

The prize has grown from improving construction efficiency to improving national productivity. This requires a next generation of BIM that supports information throughout the whole asset lifecycle, in addition to making sure that the investment already made in enabling construction efficiency continues to grow to support new capabilities such as digital transactions, modular manufacturing and the provision of services through the life of the built assets.

The Aim

The new Digital Built Britain (DBB) programme aims to create a digitally-enabled information landscape to allow the optimisation of the built environment throughout the construction, manufacturing, maintenance, operations and decommissioning phases. This landscape will also allow for the optimisation of the business services delivered through the built environment.

The following document represents the output of the DBB R&D scoping work stream informing the future digitally-enabled information landscape. Other work stream organisations and teams are acknowledged and the framework of DBB is collaborative and interdisciplinary.

This document brings focus to the 2030 horizon and summarises the research agenda required to facilitate the further exploitation of these capabilities. It is a 'scoping study'; the summary results from extensive engagement with expert academics and industrial parties and provides a 'first pass' of a provisional long-term vision that is incomplete, dynamic and subject to change (as additional learning and insights into requirements emerge in the future). The framework may be customised and developed to meet the user's specific purpose.

The aim of this vision is that: *the exploitation of data will enhance natural and built infrastructure services, driving up citizen quality of life and well-being, and commercial competitiveness and productivity*.

This exploitation of data will:

1. Provide measurable performance indicators and targets for social outcomes and through-life optimisation of key asset performance
2. Inform the design, optimisation and personalisation of citizen services
3. Inform business models and value chain/supply chain activities
4. Inform local and national policy setting

The Challenges

There are several uncertainties and challenges relating to DBB as it moves forward:

- Current lack of real feedback regarding how well the built environment performs against original design specifications
- Significant differences which exist between 'technical engineering solutions' and understanding societal outcomes
- Challenges regarding data itself

The Background

Building Information Modelling (BIM) was developed to achieve interoperability and realise efficiency in construction, planning and design. Through the work of Digital Built Britain (formerly the UK BIM Task Group) the UK has led the way and has grown a successful new construction design information services industry as a result. The UK BIM Task Group has developed the information standards required to drive efficiency in the construction sector. Elements of best practice from this are embedded in the BSI PAS 1192 suite of standards.

The development of DBB is a progression in Digital Building standards from Level 2 which is now in implementation.

Level 2c is addressing development of processes to support the use of information relating to the full lifecycle of Built Assets.

Level 3, the subject of the current DBB programme addresses the creation and adoption of the Built Environment Information Management Landscape that supports all sectors and the adoption to critical-mass of the identified target high value use cases. It supports the transition of existing assets in addition to new.

Level 4, a potential future programme, would address delivery of all services that rely on built infrastructure such that they could integrate with and derive benefit from the Built Environment capabilities initially established in Level 3.

This document includes recommendations for the next steps in further articulating the research needs for DBB with focus on Level 4 (the stage beyond Level 3 that looks to 2030+). Level 4 has a strong focus on the delivery of social and commercial outcomes through the 'intelligence' inherent in the built environment. The Research and Development stream, in focussing on Level 4, beyond the horizon of the other work streams, looked at the possible agenda which would need to be addressed during the Level 3 programme to facilitate

the further exploitation of the capabilities established by the other strands in Level 3. This stream aimed to develop:

- An understanding of the scope of the R&D required, defined by high level needs and constraints in areas such as: technological (hardware, data, and interoperability), security, cultural, etc
- Initial identification of R&D needs for L3 and L4
- Insights that are potentially useful for the other work streams
- Insights into similar international work.

The Process

The approach to completing this report comprised:

Initial desk review
This review shaped data collection processes and included research literature, industry guidance documents and standards from relevant professional institutions and standards bodies (both UK and international).

Expert Panel review
An Expert Panel was established to guide and review the work. This included a diverse representation of skills, covering leading academics, practitioners from the BIM L2 and Asset Management areas, and some sectoral representatives from economic and social infrastructure.

The Panel met twice, once after the initial review, and once towards the end of the study, with an interim offline review of the early findings. The panel reviewed and validated the findings to-date and provided guidance on gaps and uncertainties.

Co-ordination with other DBB work strands
A representative from the R&D team attended each of the weekly project review meetings to ensure consistency and identify key linkages. Representatives also attended key workshops held by other work streams, the midpoint review workshop and in the second part of the project weekly meetings were held to ensure alignment of emerging outputs, frameworks and conclusions.

Workshop 1
Prior to the workshop, the team liaised with other work stream leaders to understand the emerging vision for 2025, and early plans for achieving this. In the workshop, the DBB work stream leads presented these visions and plans, following which an initial response was elicited from leading academic in that area. The links and dependencies between the various work streams were then established and initial data collected on the gaps that need to be covered to fully deliver the vision of DBB. This information informed the development of the research requirements for each work stream and across the work streams.

Interim Report and review by Expert Panel
The interim report was used to generate briefing materials for and to guide the development of a second workshop with a wider group of stakeholders. The Expert Panel reviewed key elements of this report to test and validate them and ensure that the inputs to the second workshop were appropriate.

Workshop 2

This workshop provided stakeholders from the practitioner and research communities with an overview of the vision for DBB, and engaged them in developing scenarios for the Level 4 future and exploring possible emerging issues and related R&D requirements. Attendees for this workshop were recommended by the project team, expert panel and Client Design Authority members.

The Vision and Framework for DBB Level 4

The DBB Level 4 vision rests on the exploitation of data. This will:

1. **Provide measurable performance indicators and targets for social outcomes and through-life optimisation of key asset performance:**
    a. **How:** Developed understanding of social outcomes and trade-offs that exist between social and commercial benefits.
2. **Inform the design, optimisation and personalisation of citizen services**
    a. **How:** Accepted sharing of citizen data in a secure way. Citizens will have to feel in control of data sharing.
3. **Inform business models and value chain/supply chain activities**
    a. **How:** Adoption by larger firms will provide a large portion of the benefits; however, benefits will be maximised only when adoption occurs throughout the supply chain
4. **Inform local and national policy setting**
    a. **How:** Exploitable data is available to government, who is an intelligent user of a digitally built Britain

Level 4 will be founded on a number of key components, including:

- An advanced understanding of user needs and behaviours
- An improved understanding of how social differences affect how people engage with and benefit from data (or don't), and how there may be social differences embodied in the data (assumptions buried in its specification, collection/creation and use)
- A better understanding of how user needs and behaviours can be translated into asset and system performance measures
- User generated public data
- Public asset data
- Improved artificial intelligence and machine learning capability, and related metadata, modelling, data structures, and understanding of the implications of feedback
- Standards guiding the integration and management of the data landscape
- Standards guiding the interaction of physical activities and the data landscape
- Security protocols guiding data distribution and use
- New technical paradigms, e.g. quantum sensing and quantum computing
- New business models and procurement models.

Both the vision and the R&D landscape will be dynamic. The R&D landscape will both be defined by and inform the vision, and there will need to be a feedback loop between the two.

Analysis Framework for Generating the R&D Landscape

The different aspects of the framework will share a common backbone covering the life cycle of built environment assets:

a) Articulation of user needs and requirements
b) Conceive and Plan (including optimisation and integration)
c) Build and Commission (including optimisation and integration)
d) Manage and Operate (refine and enhance, optimise and integrate)
e) Provide valued services to users (and minimise downsides for nonusers)
f) Retrofit / Renew / Decommission (with attention to the whole cycle)
g) Assessment (feedback, optimisation and learning).

There is an intentional 'circularity' in this framework, so the final assessment phase (g) is intended to inform and support the better articulation of requirements in future.

The Trends and Drivers

Predicting the future landscape of DBB requires examination of significant and emerging themes that will drive change. These include behaviour, technologies and situations. Many of these trends and drivers have been identified and developed from a range of earlier studies and research, but are not exhaustive and are based on changeable factors.

Social

The growing, ageing population will place additional retirement/healthcare provision burdens on the state sector but also offers significant opportunities for new markets, particularly medical and pharmaceutical. This growing population will increasingly be urbanised – 70 per cent of the global population will live in urban areas in 2050 – and will increase demand for materials, water, energy and land. Resources will be subject to greater competition, with potential disruptions in their supply. In most cases, prices will rise and may also become more volatile.

Youth marginalisation – both economic and political – will emerge as a potential risk; a greater proportion of wealth, property and political power will be vested in the older segments of an ageing population with growing life expectancy than is the case even today. How the results of this inequality will manifest will depend in large part on how social policy is directed and how much effort is made to reduce marginalisation. However, if the 'digital divide' persists and remains based largely on demographics of age and wealth, it is possible that the youth of the future will be in a better position than older generation, and the more affluent than the less well off, to exploit the increasingly digital world of 2050.

Increasing costs of fuel and transport will encourage repatriation of production and 'on shoring'. This brings with it several challenges (the need to restore knowledge and skills which may be partly or wholly lost) but may be supplemented by the innovations provided by the digital future.

The impact on public services from periods of austerity may result in their being very different from today, but demand for them will go up. Increased political devolution, as seems likely today, will also have a significant impact on a range of future issues, from regulation to tax regimes, public funding, standards and perception of community.

Technological

Technology will play a central role in driving change. Some of the value being created in 2050 will derive from wholly unanticipated breakthroughs, but many of the transformative technologies, such as additive manufacturing, quantum computing and artificial intelligence, are already established or clearly emerging. When integrated into future assets and networks, the new technologies will collectively facilitate fundamental shifts in how assets are designed, made, offered and ultimately used by consumers.

Environmental

Resilience of cities and communities is becoming an increasingly important driver in the face of climate change. Climate change will have a range of impacts, including rising sea levels and extreme weather events, all of which have the potential to significantly affect infrastructure.

Focus on reduced environmental impact, e.g. greenhouse gas emissions, will promote resource productivity. Over the period to 2050, national and international responses are likely to include tougher environmental standards and new ways to price natural resources and ecosystem services.

Economic and environmental developments will result in changes in legislation, notably around emissions and sustainability. Industry will need to adapt to these, and ideally influence their creation, to remain competitive.

There is a growing need to reduce material and energy use in production. This is partly related to environmental concerns, but also reflected an expectation of increasing scarcity of energy and materials and industry's resulting inability to guarantee security of supply. One outcome of this is likely to be greater reliance on renewable resources. Food security will also be an issue, with more people to feed, less available land on which to cultivate crops and potentially harsher weather conditions.

Economic

The BRIC economies (Brazil, Russia, India and China) are likely to become collectively larger than the US by 2017 and the G7 by 2032. In addition, the 'Next-11' economies (Bangladesh, Egypt, Indonesia, Iran, Korea, Mexico, Nigeria, Pakistan, Philippines, Turkey and Vietnam) are likely to become collectively larger than the US and almost twice the size of the Euro area by 2050. The UK's role in this changing world will rely on its ability to compete in the new global marketplace. (Foresight (2013)).

Mass personalisation of low-cost products will be possible on demand. The historic split between cheap mass-produced products creating value from economies of scale and more expensive customised products will be reduced across a wide range of product types.

ICT-based systems are facilitating new business models based on shared use of assets. This shifts the business model from ownership to access, incentivises manufacturers and constructors to provide robust products, and allows the creation of new service-based revenue streams. We will see the emergence of a 'circular economy' in which end–of-life products are reused, remanufactured and recycled. Resource scarcity and higher costs for energy and waste disposal will shift value creation to new models.

Continued global fragmentation of the value chain will include the outsourcing of functions and offshoring.

The rise of the digital economy and an associated increase in customisation will have an impact on traditional assets.

New business models will continue to emerge. The service model is increasingly replacing asset ownership, and attention to the circular economy and environmental sustainability will be critical differentiators. New business models for service value creation and risk-sharing must be supported by trusted and secure data and information.

Patterns of global trade and investment will determine the relative importance of the countries to which the UK exports and from which it imports; the types of firms and sectors which will be involved in its trade; the future structure and performance of manufacturing within the overall Balance of Payments; the place of the UK in the global pattern of foreign direct investment (FDI) flows; and the conduct of R&D and investment in innovation.

By 2020 there are expected to be an additional 80,000 managerial, professional and associate professional and technical positions in UK manufacturing, and millions more globally. By 2050, this number will be significantly higher. Overall, many jobs will require apprentice, degree and technician level STEM qualifications, especially in product design and development.

Industry-specific

Within the construction industry itself are a range of more near-term and specific trends which DBB will need to encompass:

- A greater understanding of the wider approach to whole-life management of built assets, related to the understanding of the value of assets, along with asset whole-life value management
- Standardisation of data and information capture, storage and transfer within whole-life asset management, e.g. the transfer of data from Capex to Opex, and an increasing need to find effective ways to verify information quality and completeness (e.g. via machine verification)
- Development of information requirements, alignment of organisation and asset information requirements as per PAS 1192 and ISO 55000 standards

- Development of whole-life standard information requirements from Plain Language Questions; continuing discussion and search for alignment on Level of Development, Level of Accuracy and other Lo*X*
- Development of BIM models as per whole-life elements, e.g. modelling track into the lengths it will be maintained; adoption of the digital twin
- Tagging in Asset Information Model as per the physical world; direct link from the digital model to the physical asset
- An increase in public expectations of connectedness, as well as demand for public services
- Digital tools become more cost-effective, but there must be a drive for greater clarity about through-life value and cost effectiveness and not just initial cost
- Merging of BIM and GIS and of BIM and Lean

Research needs, the Research Landscape and future directions

The work of the scoping study explored the current research landscape, general research challenges to be faced and future research topics. The following summarises in condensed for the findings from the scoping study.

In thinking about both the current landscape and candidate directions for future capability building there are some overarching imperatives. These include:

Managing the research lifecycle

- Building stakeholder alignment to enable UK leadership in research and development of capability
- Finding ways to measure and characterize achievement of L2 and L3 and developing leading indicators to purposefully manage the transition to L4
- Maintaining agility in the specification and targeting of research
- Building 'development' and 'delivery' capability (as well as conducting the initial research)

Assuring accurate targeting and coverage at the right depth

- Exploring the breadth of the DBB vision to ensure inclusion, covering urban and rural, beyond 'buildings' to 'constructed assets', and covering practices as well as tools
- Ensuring adequate coverage of the social, political and cultural aspects of DBB, its outcomes and its implications, exploring nuances of each of the three aspects
- Gathering information and insight from those most closely associated with the developing Architecture Engineering Consultancy industry to ensure a complete set of perspectives.

Learning from prior experience

- Learning from other industries / countries
- Learning from past projects where all the determinants of trust and collaboration were in place and underpinned success
- Learning from adjacent research activities such as the RCUK Digital Economy programme

- Understanding the context of adjacent industries; making specific demands on DBB, coupled to DBB or competing with DBB for skills and resources

Addressing specific aspects in the move to higher levels of BIM

- Looking at the implications of asset life-cycle, and being wary of allowing a focus on where costs fall blinding parties to the issues of total value and total expenditure
- Understanding the lifecycle of services from DBB and finding ways to specify and manage the lifecycle of DBB assets in support of the full lifecycle of such services
- Paying adequate attention to the full gamut of data quality, data security and data management issues as well as to the tools and techniques of BIM

Reviewing the landscape and considering the future prompted clustering of high level domains as well as a multiplicity of specific topics. These domains then offer broad themes of capabilities to be developed, building on current research activity. They include:

- **Social aspects** – how the future DBB will discern the needs of the widest range of stakeholders and deliver
- **Lifecycle management of** assets – considering all aspects of the built environment assets and the relationships between actors and their concerns through the assets' lives
- **Value drivers and business modelling** – exploring how data and its management could change perceptions and realisations of value
- **Data utility** – exploring the issues of how data is used, its attributes and those aspects which make it of most utility
- **Platforms and tools** – considering the technical aspects of how data is curated and used
- **Security, robustness, resilience and safety** – addressing these as topics of particular concern today
- **Policy, Legislation and Regulation** – the context around data and its application in DBB, from philosophy to pragmatic impact
- **Education and capability building** – exploring the implications of broader and deeper, more sophisticated use of data and the abilities to add and extract value

We turn now to consider these in detail.

SOCIAL ASPECTS

DBB will need to consider how the built environment and the data that underpins it will impact on society and the demands society will make on the build environment. Current research covers, inter alia, topics such as:

- **Social impact of technology implementation -** especially of fast-paced change on social values.
- **Measuring social performance -** assessing the process of making an organisation's social vision into a reality.
- **Language, texts and society -** how language and text is changing within an increasingly digital society and what this might mean in specifying and achieving value.
- **Discrimination in the digital economy -** its prevalence within online digital marketplaces and how best to tackle it.

- **Gender and identity -** how the advancement of digital practices are influencing the diversity of human beings.
- **Culture of digital economy -** technology both in an artistic and cultural context, with respect to the digital economy.
- **Data-led cultural enterprises -** understanding cultural enterprises and how they are changing with the advancement of data and information.
- **Rural digital economy -** how their specific characteristics create challenges around issues such as quality of life and wealth creation within a digital economy.

With this context in mind, the scoping study identified the important future research topics of **exploring and understanding stakeholder groups** and thus how they might engage with DBB and its data-enabled services. Examples include the different groups of actors in the 'industry', non-users of DBB-enabled social systems as well as users, the engaged and the less engaged, the impact of generational differences and variations in values, motivations and behaviours.

LIFECYCLE MANAGEMENT OF ASSETS

Obviously DBB centres on the integration of the concerns through-life of the built environment and the data that enables broader optimisation to be pursued with a better understanding of the full costs and benefits involved, applied to the widest range of stakeholders. This implies an interest in the following research topics.

- **Demand modelling -** exploring better ways of using modelling methodologies (processes, tools and data) to predict demand on a system such as a rail network, or on a building such as a new office block.
- **Project delivery systems -** exploration of projects as a system of systems for delivery, including integrated strategies, information controls, component design and assembly.
- **Automation of construction and operational processes -** examining how to promote process efficiency by automating key stages within the construction and operation activities through life.
- **Design of Smart Cities and infrastructure systems -** understanding the selection and management of information being gathered from indicators (transport, environment, services, etc.) to improve design, decision-making and optimisation of services.
- **Management of Smart Cities -** exploring information and the principles of management within the context of urban infrastructures and smart urban technologies.
- **Physical mobility in a Smart City -** examining the data needs and data management to optimise and support the mobility (across all scales) of people, across the whole range of purposes, and of personal capabilities within a smart city.

Looking to the future, such topics need also to consider the special needs of urban environments, of transport nodes, and of linear assets. Some specific topics identified in the scoping study include:

- **Specification formulation and negotiation** - examining the issues and developing candidate solution paths for making a transition from ill-understood and barely perceived requirements and constraints to a robust specification, spanning procurement and operations and including social targeting and trade-offs between 'outcomes'.
- **Research topics which address the 'transitions'** - concentrating attention on the transitions from "Design" to "Build" which is difficult and from "Build" to "Operate" which is significantly more so. All the

elements have not yet been identified, let alone how to digitize them. Address issues as static data is replaced by dynamic data and explore issues of feedback across transition boundaries.

- **Understand the balance of consequences on-site vs off-site** - considering the different forms of manufacture/fabrication and understand how to optimise these.
- **Industry culture -** discerning and understanding industry actors' approach to reward, to resolve the current rewards and incentives for each party in the industry, the trade-offs between them now and potentially in future; exploring communications, especially of feedback loops; negotiation and conflict management; collaboration and cooperation; interoperability and change management; and differences as service providers in L4 become part of the ecosystem.

VALUE DRIVERS AND BUSINESS MODELLING

Because DBB needs to consider the widest range of stakeholders the drivers of value (directly financial and otherwise) it is important to marshal the capabilities from research topics such as:

- **Economy and capitalism -** since the economy in a broad sense is the production and consumption of services and goods within a state of a country or region, means for monitoring and measuring, together with managing the inevitable multi-aspect trade-offs will be important.
- **Digital business models -** research focused on new and emerging commercial business models and the advancement of information exploitation.
- **Totex (Total expenditure) delivery framework -** exploring the delivery and procurement of the built environment throughout the whole life of assets, and not just the design and construction phases.
- **Understanding the value of Smart Cities' data -** understanding the economic, social and environmental benefits of smart cities' infrastructure and generated data.
- **Improving business performance with advanced GIS -** exploring how business performance and social benefit can be improved with the used of advanced GIS.

Building and extending these topics, DBB needs also to be informed by research into domains such as:

- **Business models, value, commercial relationships** - understanding how value is assigned to information is a crucial topic because perceptions of value will enable or inhibit sharing, because value emerges when data is "transacted", and because there is a need to develop ways to better discern where the value lies and to forecast and influence which actors will expropriate the value (or benefit from such value). Sub-topics include; explore how data taxonomies can be related to the value of data; negotiation of social value; contract theory and commercial models and risk-based approaches.
- **The shift to services** - in a world where there is a continuing shift from ownership to services and where there are lessons to be learned from leading protagonists (for example the UK MoD's shift in procurement from objects to availability of capability) there is research to be done about changes in business models, management tools, commercial relationships, and processes together with the underlying information landscapes to enable the shift.

DATA UTILITY

Current research addresses many of the aspects critical to data use which will matter to DBB, including:

- **Digital transparency -** addressing the need for transparency within the digital environment, and achieving visibility of agenda and provenance.
- **Data collaboration tools -** exploring new technologies to support the collaboration process.

- **Data performance metric processes -** exploring and optimising the metrics used to track, monitor and assess the success or failure of data performance.
- **Information validation and assurance -** exploring approaches to assure provenance and that information is clean, correct and fit for purpose, irrespective of source.
- **Data contracts and containers -** understanding new options for data value exchange and data locations (contracts and containers is the concept of having personal data stored on the customers' side, rather than on a centrally-owned database.)
- **Information & data interoperability capabilities -** looking at the need for greater information and data interoperability capabilities throughout the whole life of the asset, strongly focused within the design and construction phase for the architecture, engineering and construction (AEC) industry.
- **Open Data Platform -** understanding the implications and impact of the ODP (an industry-led initiative that provides a common platform for big data common development and deployment of such developments).
- **Data discrimination** – exploring the implications at many scales, from policymakers inadvertently using data that misses a section of society to the processes of selective filtering of information over a network.
- **Spatial data usability-** examining the factors that impact on the appropriateness and suitability of spatially-referenced data for a range of typical GIS-based tasks.

It became clear from the scoping study that there are other aspects of data and its management which will need research to underpin new and relevant capabilities for DBB, including:

- **Specifying data and measurement needs, information content and meaning** - understanding the nature of data / information and the value(s) embodied within its specification, collection, management and use / manipulation / exploitation. Exploring the politics, ethics, ownership, copyright and use as well as the technology of data. Augmenting large and small scale data sets. Using data across 'fleets' of assets.
- **Metadata** – a domain in its own right - exploring and integrating prior work and then extending to cover topics that include ontologies and information organization; the impact of the Internet of Things; linked data, open data, big data and user-generated metadata; metadata standardization, authority control and interoperability.
- **Explore data management research**, especially considering, for example, the semantic web and its supporting technologies (metadata and operating agents), data fusion, graph-data structures and their query tools, massively parallel data sets, cloud-native applications as a route to management of linked / accessible data sets, and the creation of digital assets of the 60% of infrastructure & buildings that exist today for use in 2050.

PLATFORMS AND TOOLS

This area considers more the technical than the managerial or social aspects of DBB and will, of course, be a core building block with a lot going on already, including:

- **IOT environment and platforms -** research into and development of both hardware and software (on-board & server side) analytics for the Internet of Things (IoT) and smart environments.
- **Networks as a service -** research looking at trends within manufacturing and service providers such as Amazon, who have created entirely new ecosystems to provide a full set of services (B2C and B2B), and understanding the lessons, tools and methods that might carry across.

- **Advanced data spatial services -** research focusing on the application of data visualisation techniques, spatial relationships and data mining technologies and the interaction between developments in each of these domains.
- **Smart Cities mapping tools -** a research topic that specialises in the mapping of urban centres for economic, social and environment visualisation.
- **Smart Cities sensors -** research into the emerging technologies that will enable real time information collection and exploitation within a complex system.

This very rich area is one that will be driven naturally by the evolution through BIM Level 3 and is the one most likely to be conditioned by commercial drivers. Therefore review of the scoping study suggests that future DBB research should focus primarily on the adjacent topics which will provide insights and capabilities within which commercially driven research can flourish.

SECURITY, ROBUSTNESS, RESILIENCE, AND SAFETY

As with so much of the digital world, in the context of DBB as well, there are serious concerns about the risks of exposure to new hazards and thus research topics that include:

- **Security in the cloud -** exploring the broad set of policies, technologies and tools (developments), which are focused on protecting and supporting the associated data, applications and infrastructure of cloud computing.
- **Trust in data collection and storage -** research which spans the themes of criminology, sociology, law and cultural studies to better understand issues of trust.
- **Information risk management -** exploration of the many challenges and opportunities that result from organisations' needs to control and protect information within the context of a system as complex as that envisaged for DBB.
- **Cyber-attacks on infrastructure -** exploring the hazard, the defence against, and the response to cyber-attacks on infrastructure systems and assets, such as a railway network or an airport.
- **Digital forensics -** research to underpin capabilities in the recovery and investigation of material found on digital devices, often relating to cyber-crime activities.

POLICY, LEGISLATION AND REGULATION

Much of the successful development of DBB in future will depend upon the legislative, regulatory and policy frameworks in place, and these will have a profound impact on the UK's competitiveness. So topics of research include:

- **Rights and justice -** exploring how best to ensure that rights and the meaning of justice is maintained within a digital society.
- **Privacy, trust, ethics -** exploring the needs for privacy, trust and ethics within the domain of construction law and regulations and how best to meet such needs
- **Law and legal requirements -** looking at the role of science and technology within contemporary societies and the influence of such developments on politics, law and legal requirements, with much that is of direct relevance to DBB.
- **Data-driven policy -** research into policy mechanisms and tools that use a data-driven decision management (DDDM) framework that potentially enables decisions that can be backed up with verifiable datasets.

- **Smart governance and standards -** work focused on the development of 'smart' data-driven policy, standards and tools which aid in the development of a smarter, better informed government, all arising from the emergent smart cities agenda.
- **GIS in public decision frameworks -** exploring how to apply Geographic Information System techniques in a collaborative environment, aiding in decisions made by government and organisations with the wider public.

Future research directions will continue these topics, augmented by a systems and through-life perspective.

EDUCATION, TRAINING AND CAPABILITY DEVELOPMENT

The move to a digital future could well create losers as well as winners among those who fall behind or who lack the ability to acquire the digital skills necessary to embrace and exploit the opportunities from DBB. This could apply to the broader society of users of the built environment, to workers along the supply chain, to companies that fall behind, in fact to all who find it difficult to step into the new world. The issues will be about education, learning and capability development in general and certainly about digital skills. A particular topic highlighted during the scoping study was:

- **Digital security education -** exploring the most efficient way to deliver educational platforms that allow for dynamic and bespoke learning opportunities to a broad range of diverse communities on the topic of digital security.

The industry as a whole faces future issues in **integrated learning** along whole supply chains and across cohorts of learners. There is the task to explore learning practices from other domains, especially those which have accelerated already.

Building on and developing the above themes suggest future directions of work that include:

- **Risk Management** - research to explore the implications of achievable "commercial reliability", avoiding or overcoming the commercial disincentive of disclaimed liability and responsibility (part of the risk management agenda), and finding ways to manage or trade risk that are constructive and add value.
- **Checking the potential offerings from 'Systems of Systems' research** - exploring and extending topics already under development in SoS research including, for example, design, for resilience, failure modes (especially cascade failures), and recovery options.

The Timeframe

The work presented in this document is at an early stage and differs in timeframe to other DBB work streams but there are clear linkage points.

The academic response – provided by consultation with the Expert Panel, from literature review and from engaging with the community through workshops – supported many of the conclusions reached across the work streams. It was noted that the issues to be faced were not limited to technology and business practices, but had a huge social and cultural component which would need to be addressed holistically and with a mind to unintended consequences.

The main connections consistently emerging from the various work streams included:

- the need for trusted data
- the need for new business models
- the need for standards
- recognition that DBB is about enabling rather than designing
- understanding that people will react in unforeseen ways.

The Gaps in Capability and Exploitation

A significant point highlighted consistently by the Expert Panel was the necessity for Government to not only support the R&D component of DBB but to be actively involved in promoting the adoption of all DBB levels into practice.

To consider:

Widespread adoption of information management systems requires compelling advantages of and incentives for demand and delivery, and a critical mass of users. The supply chain requires incentivisation to deliver outcomes essential to reduce lifestyle impacts. There needs also to be a focus on pursuit of value rather than on minimisation in cost.

The benefits to be obtained and the incentives that drive the uptake of the elements of the new DBB will vary across the sectors, across the supply chain and across the stakeholders. It will be important to obtain buy-in from all constituencies.

Skills shortages in the UK would need to be addressed. Automation will continue to bring challenges on this front, alongside the many benefits it brings on others. Job roles will change, and the established workforce will have to adjust in the face of new demands. New processes will demand systems integration skills, particularly between ‘build’ and ‘operate’.

One current capability gap identified is the efficient collection and use of data in which standards and regulation may pay an important role.

To consider:

The construction industry gathers large quantities of data, but fails to do so in a way that enables the value of the data to be extracted; lessons should be taken from other industries about reducing the frictional costs of harvesting data. A shift is needed from an ‘asset-centric’ approach to a ‘human-centric’ orientation in order to deliver value at Level 4.

To ensure consistency of data and data standards, it is thought that top-down mandating often works better than enlightened self-interest, although it may be possible to make standards so ubiquitous or compelling that people use them without a mandate; this will depend upon a dialogue between standards

setters and users. It is essential to prevent standards building barriers between phases of the constructed asset's life and the actors involved.

The Next Phase

Looking ahead, DBB will need a 'bridgehead' between the DBB project and the UK research community to maintain the research landscape, build a relationship with the UK research community, and enable results of cutting edge research to be fed into the DBB programme and into professional practice.

The role of the bridgehead will include: engaging with stakeholders to understand the requirements of DBB Level 3 and Level 4; identify relevant current research to address those requirements; strong engagement with the UK research community for input to research needs and vision, to include UKCRIC and The Alan Turing Institute; advise HM Government and the UK Collaboratorium for Research on Infrastructure and Cities (UKCRIC) regarding scale and scope of the required R&D programmes; seed fund small collaborative research projects to enable development of 'proof of concept' collaborative research ideas and identify the 'use cases' which will deliver value from the underpinning research.

The bridgehead will effectively be managing the identification and delivery of the research programme, and harnessing the value of the research. It will actively feed in to the wider development of DBB, and gather research requirements from the wider DBB programme. It may have a small number of researchers based within it, carrying out relevant research. These researchers may be post-docs or other early career researchers.

The bridgehead will link to:

Academic community
Due to the uncertainty surrounding the vision for Level 4 and that it will be informed by ongoing research, it is vital to engage the research community. One good model is the EPSRC's Network model which provides funding to bring together researchers, industry and other groups to develop collaborations through workshops, visits and coordination. It is recommended that the bridgehead adopt this operating model.

Wider stakeholder community
The bridgehead will gather input from the stakeholder community to shape the research requirements, and to translate outcomes of research for the stakeholder community to that they can influence the development of DBB and be successfully brought to implementation in practice.

Governance – Expert Panel
A panel of experts who meet regularly will guide the activities of the bridgehead.
An Expert Panel is already advising on the R&D scoping projects and this panel should be augmented for the next phase of work and reflect the wide agenda which DBB Level 4 will need to address.

The Next Steps

A further scoping programme will be carried out over a period of four to six months to develop a more detailed assessment of the current research landscape, the future research requirements and other areas this scoping phase has been unable to address fully. This next phase of work should include some initial research network consultation exercises to start to build an academic community around Level 3 and 4.

At the end of this period, specific detailed recommendations will be made regarding the first phase of R&D funding calls, the scale and scope required of these calls, and the detailed requirements for the bridgehead, including staffing requirements, proposed operational models and engagement activities.

It is anticipated that the bridgehead would be able to be formally commissioned in March 2018.

The DBB Network

If you require further details about this R&D scoping study, or you would like to be part of the collaboration that is DBB, please contact: www.cdbb.cam.ac.uk