

Year One Report

Towards a digital built Britain



Foreword



Robin Webb Deputy Director, Infrastructure and Procurement, Department for Business, Energy & Industrial Strategy (BEIS)

> It has been an important year in the digital transformation of the United Kingdom. The government has set out ambitious objectives in order to build a Britain fit for the future for the benefit of all citizens, and the Centre for Digital Built Britain (CDBB) plays a critical role in our goal to digitally design, build, operate and integrate the built environment. I am delighted to present this year one report, highlighting progress thus far.

It is a very important challenge, and a very exciting one. To realise the opportunities offered by the digital transformation of the built environment requires partnership in which the UK's world-leading firms and academics can come together with the public sector. I hope and believe that CDBB will increasingly be the enabler and the go-to place for this kind of collaboration.

An early example is the work of the Digital Framework Task Group. Convened by CDBB the Group has made an important contribution to the development of a national digital twin for infrastructure with the recent publication of the Gemini Principles, delivering on the recommendation of the National Infrastructure Commission (NIC) in its report Data for the Public Good.

"To realise the opportunities offered by the digital transformation of the built environment requires partnership in which the UK's world-leading firms and academics can come together with the public sector."

> Robin Webb Deputy Director, Infrastructure and Procurement, Department of Business, Energy & Industrial Strategy (BEIS)

Looking to the future, the delivery of the Core Innovation Hub (CIH) by the Transforming Construction Alliance (TCA) represents an important step towards increasing the effectiveness of investment in economic and social infrastructure: a cornerstone of the Infrastructure and Projects Authority's Transforming Infrastructure Performance programme. The TCA brings together the existing facilities, collaborative networks and specialist expertise of the Manufacturing Technology Centre (MTC), Building Research Establishment (BRE) and CDBB to enable a national focal point for the research, development and innovation needed to deliver change. The CIH will be a catalyst for transforming the UK construction sector through manufacturing technologies and digital ways of working that will ultimately benefit people, places and the business environment for years to come.

Last, I would like to take this opportunity to thank all in the wider CDBB community for their support and contribution and invite those with a stake in the digital transformation of the built environment to become involved. I hope that you enjoy discovering the CDBB's year one activities through this report.



Department of Health interior refurbishment project - reference page 63

Introduction



Professor Andy Neely Director of CDBB, and Pro-Vice-Chancellor for Enterprise and Business Relations

> Creating a digital built Britain represents a huge opportunity for the UK. It has the potential to transform our construction and infrastructure sector, to make it more efficient, more productive and more environmentally

I am also delighted that, as we approach the end of our first year, we have been able to sustainable while improving the quality of life announce CDBB's role in a major new initiative: for everyone in the UK. the Core Innovation Hub. CDBB has partnered It is both an exciting and enormously complex with the Building Research Establishment and task, which, if we are to achieve it, needs a the Manufacturing Technology Centre to form huge number of people and organisations the Transforming Construction Alliance. In to work together around a shared vision. November it was announced that the Alliance I was delighted when the Department of has been awarded £72 million in funding Business, Energy & Industrial Strategy asked from the Industrial Strategy Challenge Fund's the University of Cambridge to take the lead in Transforming Construction programme to making this happen. help the sector harness manufacturing and digital technologies and, by doing so, reinvent In many ways, Cambridge is the natural home the way it designs, builds and operates new for such a cross-sector, cross-discipline, crossbuildings and infrastructure projects and organisation endeavour. We already have a integrates them into the built environment.

huge range of research activities and industrial collaboration taking place. The Centre for I would like to thank everyone from Smart Infrastructure and Construction has government, industry and the academic been making great progress in developing the community who has embarked on this journey digital infrastructure for the sector, and the with us. Our ambition for the sector will only creation of CDBB has given us the opportunity be realised if we all work together to achieve to build on that progress by creating a truly it. We have, therefore, been gratified by the interdisciplinary programme spanning the support we have received this year, arts, humanities and social sciences, as well as which has allowed us to accomplish an technology, medicine and all the sciences. enormous amount in a short space of time. I look forward to seeing CDBB and its partners But CDBB is not a Cambridge programme; it continue to make rapid progress in this is a national programme. We have been in a important national task.

uniquely privileged position to fund research projects in universities throughout the UK. The enthusiastic response we received has, in a very short space of time, enabled us to grow an active and engaged research community across the UK.

To design, build, operate and integrate better buildings needs a "golden thread of information". Another important strand of our activity has been supporting the take-up of effective information management across the sector. The next chapter in this story is already unfolding as we work to put in place the principles and frameworks that will support the development of a national digital twin.

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The Centre for Digital Built Britain has been tasked with ensuring that the UK is able to harness new technologies and digital connectivity to transform the built environment and deliver real social and economic benefits to its citizens.

Introduction

Towards a digital built Britain

The "digital revolution" gives us the opportunity to reimagine our buildings and infrastructure, to rethink both how they work and how we use them. Following from the government report, Data for the Public Good, the Centre for Digital Built Britain (CDBB) has been tasked with ensuring that the UK is able to harness these new technologies and digital connectivity to transform the built environment and deliver real social and economic benefits to its citizens.

Since the publication of its 2011 Construction Strategy, the UK government has demonstrated its commitment to the sector through a series of policy interventions, including a pledge in its 2017 Industrial Strategy to double its spending on infrastructure projects over the coming decade to £600bn.

Globally, the infrastructure sector is worth \$2.5 trillion annually and this figure is expected to rise to \$49 trillion by 2030¹. Through the publication of its UK Industrial Strategy and Construction Sector Deal, the government has set clear ambitions for the UK to be at the forefront of that expansion, creating new jobs and prosperity for its citizens.

Why is construction attracting all this attention? As a sector, it represents a significant opportunity for economic growth. At the same time, the sector has suffered from inefficiencies and persistently low levels of productivity, largely the result of a fragmented supply chain, which has hampered its ability to embrace innovation and change. By tackling these issues, the government anticipates it could make savings of £15 billion a year². The sector also has a pivotal role to play in reducing the UK's harmful emissions and in moving towards clean growth and a more circular economy.

In its White Paper Construction 2025, the government has identified robust targets that reflect its aspirational vision for the future of the sector.



Improvement in exports 50% reduction in the trade gap between total exports and total imports for construction products and materials

Lower costs 33% lower costs across both the initial cost of construction and the whole-life cost of built assets

Faster delivery 50% reduction in the overall time, from inception to completion, for new-build and refurbished assets

If it achieves these targets, the sector will have made a major contribution both to the UK economy and its efforts to tackle climate change. But the vitality of the sector is important in other ways. Getting the right infrastructure and buildings on time and at the right price is critical to everyone who lives and works in the UK.

¹ McKinsey Global Institute (2016) Bridging Global Infrastructure Gaps http://www. mckinsey.com/industries/capital-projects-andinfrastructure/our-insights/bridging-globalinfrastructure-gaps ² Infrastructure and Projects Authority (2017) Transforming Infrastructure Performance. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/664920/transforming_infrastructure_performance_web.pdf Good road and rail networks, fast broadband, clean energy, safe water, school buildings that encourage learning, hospitals that support healing, high-quality, affordable housing and offices that promote productivity and well-being: all of these things not only drive economic prosperity, they define how we live our lives.

What is a digital built Britain?

Building information management (BIM) and improved information management in the construction sector represent a huge step forward. However, if the UK is to harness the full potential of new digital technologies such as the Internet of things, digital twins, AI and advanced data analytics across its built environment, it needs to think more expansively. BIM Level 2, using the PAS 1192 standards, is helping us design and build more efficiently but if we are to move to the next generation of user-centric buildings we need to be ambitious in our aspirations – and be able to explain them clearly. This is why CDBB is changing the language from BIM Levels 2, 3 and 4 to Design, Build, Operate and Integrate in order to catalyse transformation across the sector.

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Design

Use best practice, secure by default, information management and digital techniques to get data right from the start and design better-performing homes, buildings and infrastructure.

Build

Exploit new and emerging digital construction, information management, and manufacturing technologies and techniques to improve safety, quality and productivity during construction.

Operate

Use effective information management to transform the performance of the built environment and the services it delivers.

Integrate

Understand how the built environment can improve citizens' quality of life and use that information to drive the design and build of our economic and social infrastructure and the operation and integration of the services they deliver.

How CDBB supports the digital transformation of the built environment

How is CDBB making this happen?

CDBB is a national programme, coordinated by the University of Cambridge and run in partnership with the Department for Business, Energy & Industrial Strategy (BEIS).

Our aim is to champion the digital revolution in the built environment by developing a shared vision of the future and supporting the consistent adoption and promotion of effective information management and digital transformation.

It is doing this across three coordinated programmes:

Policy - Working with government to develop the right evidence-based policy framework, and encouraging knowledge sharing and consistent procurement to drive the journey to a digital built Britain.

Research - Growing an active UK research community to develop new technologies and new ideas and promoting collaboration across disciplines and across universities. Engineers, architects, computer scientists, mathematicians, economists, psychologists, sociologists, and anthropologists (among others) are coming together to reimagine the future of our built environment.

Change and knowledge exchange

Working with industry bodies and individual firms to test those new ideas and help put the best of them into practice by demonstrating their value, sharing good practice, supporting organisational change, developing common standards and certification and providing education and training.

Home Nations Working Group

David Philp Chair

Ensuring that the benefits of effective information management are shared across England, Scotland, Wales and Northern Ireland is the remit of the Home Nations Working Group (HNWG). Formed in 2018, it brings together the four UK national BIM programmes to develop a consistent approach and to promote our vision of a digital built Britain.

Public Sector BIM Working Group

Chair Terry Stocks - Head of Level 2, CDBB

One of CDBB's tasks is to help BIM and effective information management, as defined in the 1192 suite of British standards, to become "business as usual" within central government departments, their supply chains, and ultimately across the whole UK construction sector. It does this through its work with the Public Sector BIM Working Group, which brings together the delivery leads of the central government departments to share good practice and ensure consistency.

Digital Framework Task Group (DFTG)

Mark Enzer - Chief Technical Officer, Chair Mott MacDonald

The DFTG was launched by HM Treasury in July 2018 to steer and guide the successful development and adoption of the Information Management Framework for the Built Environment. The framework will establish the building blocks to enable effective information management across the built environment and will pave the way for the development of the national digital twin. The DFTG is made up of senior leaders from industry, government and academia.



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Chapter 1

Informing Policy

Creating the national digital twin



Introduction: Mark Enzer Chair of the Digital Framework Task Group

The government has set out an ambitious vision for the construction industry and, through the construction sector deal, has made a clear commitment to its transformation. In the same vein, the government's positive response to the National Infrastructure Commission's Data for the Public Good report opens the way to deliver a number of visionary recommendations, including the development of the national digital twin – an ecosystem of digital twins connected via securely shared data.

In the context of digital built Britain, digital twins are realistic digital representations of assets, processes or systems in the built or natural environment. Essentially, they enable better decision-making throughout the whole-life of assets and systems - their delivery, operation, maintenance and use. In this way, digital twins offer real value; connected digital twins promise even more. But such connectivity will require secure resilient data sharing across the built environment, and this will be a key part of effective information management across our industry. Our first challenge, therefore, is to create an information management framework that will enable secure interoperability across the built environment and this will provide the foundation for the national digital twin. To take this forward, CDBB has established the Digital Framework Task Group (DFTG). As its first deliverable, the DFTG has published the "Gemini Principles", which sets out the high-level definitions and principles for guiding the development of the framework and the national digital twin.

The importance of industry alignment and leadership

As part of a shared vision, we need to recognise that we are part of an informationbased industry in which better decisions, based on better data, lead to better outcomes for the ultimate customers - our citizens. And we should remember that this applies not only to the delivery of new infrastructure, but also to the infrastructure that we already have. Many industry bodies and organisations across the sector already recognise the importance of digital transformation and are taking coordinated steps to change. For example, the Infrastructure Client Group, which includes many of the most important infrastructure clients in the UK, is providing important leadership in this area. It has formed the Digital Transformation Task Group, with representatives who are leading on the development and implementation of digital transformation strategies. Transforming the industry is complex and it needs these kinds of coalitions to provide leadership and help foster industry alignment. In this context, CDBB has a critical role to play in bringing the sector together around a shared vision, in acting as the custodian of the UK's standards for information management in the built environment, and in providing practical evidence-based support for those engaged in the transformation.



Exchequer Secretary to the Treasury, Robert Jenrick, announcing the launch of the Centre for Digital Built Britain's Digital Framework Task Group during a visit to the University of Cambridge, July 2018.

"We are asking the Centre for Digital Built Britain to launch a new task group, to help us realise the full value of data for UK infrastructure. The group will advise on how we can set common standards and tear down barriers to data sharing, all to increase the efficiency of construction projects and deliver high-performing infrastructure fit for the twenty-first century."

> Robert Jenrick MP Exchequer Secretary to the Treasury

Building the digital foundations:

UK BIM programme update

The UK continues to lead the world in the adoption of informational management in construction projects. Since the publication of the government's 2011 Construction Strategy, information management has been, and remains, central to its digital construction strategy.

Much has been achieved since then. By making information management at BIM Level 2 mandatory for all centrally procured government construction projects in 2016, the government has already saved billions of pounds' worth of public money.

As a result of the UK's leadership in this field, the British standards for information management are about to be promoted to international standards. This will put the UK in a very strong position when competing for its share of the global construction market.

CDBB is working in partnership with industry and the government to support and coordinate the consistent adoption and promotion of effective information management and digital transformation through its working groups and international programme.

BIM glossary

What is BIM?

Building information modelling (or BIM) is a set of digital tools, processes and standards for information management used to capture and store the data associated with a construction project so that it can be shared by everyone working on the build and those responsible for the assets' subsequent operation.

What is BIM Level 2?

BIM Level 2 is the use of collaborative information management on a construction project, where all project and asset information, documentation and data are kept and shared digitally in compliance with the 1192 suite of British standards and associated industry documentation.



What is the BIM Level 2 mandate?

The government's 2011 Construction Strategy included a policy commitment that BIM Level 2 be used on all centrally procured government construction projects from 2016, which is widely referred to as the "mandate".

What was the UK BIM Task Group



The UK BIM Task Group was formed by BEIS with industry under the Construction Industry Council in 2011 to support central government departments and their supply chains with the adoption of information management, in preparation for the 2016 so-called "mandate", and to work towards this practice as "business as usual" beyond the mandate. In 2017 the BIM Task Group was wound up on completion of their task and custodianship of the UK BIM programme was transferred to CDBB to be incorporated into the UK's wider digital programme.

Building the digital foundations:

BIM and effective information management





Terry Stocks Head of Level 2, CDBB

Fiona Moore Level 2 Programme Manager, CDBB

Information management sits at the heart of digital transformation across the UK built environment. It will enable us to dramatically improve both delivery and performance efficiencies by stimulating more innovative capital and operational delivery methods. One of CDBB's tasks is to help BIM Level 2, as defined in the 1192 suite of British standards, to become "business as usual" within central government departments, their supply chains and ultimately across the whole UK construction sector. It does this through its work with the Public Sector BIM Working Group, which brings together the delivery leads of the relevant central government departments to share good practice and ensure consistency.

Establishing effective information management is essential if we are to move to a digitally built and operated Britain. The construction industry faces big challenges; we must increase both the number of people choosing construction as a career path and the skills of the construction industry professionals, including those already working within the industry. This is an ageing sector. The Construction Industry Training Board reports that 400,000 skilled workers will reach retirement age in the next 10 years. That is in addition to the estimated 182,000 jobs needed in the sector over the next 5 years. The Q4 2017 RICS UK Construction Market Survey poll found more than 60% of respondents thought the skills shortage would affect growth and output in the future. These shortages will put pressure on plans for a high-performing construction industry that delivers significant growth. The UK government has made a number of commitments (including the creation of CDBB) to keep UK construction at the forefront of technology and improved output. However, if our skills don't keep pace with these aspirations, we risk failing to meet the ambitious targets of better, quicker, cheaper, greener.

The UK approach to information management and digital construction gives us the means to reach these targets. The government's drive towards effective information management will deliver numerous benefits, including: the ability to engage more effectively with stakeholders and suppliers, then when aligned with government soft landings, the ability to better define and in turn measure the performance outputs required, the ability to manage information in order to protect it and not have to repeatedly re-procure it, to name just a few.

How will information management help industry tackle its skills challenges?

Information management and digital transformation will catalyse a move away from traditional trade-based skill sets, where there are significant shortages, to a growing technical requirement for BIM proficiency, logistics and manufacturing.

We need to promote construction to a wider community. The use of digital tools, including 3D modelling and information management, introduced in schools and college construction courses, will show that construction is a high-tech industry, supporting the digital built Britain, smart cities and smart building agendas.

How is CDBB supporting broader adoption of information management?

CDBB is building a library of resources to support the adoption and good practice use of information management in the construction and infrastructure sector on its website, including the publication of a BIM Benefit Measurement Methodology to demonstrate the value of BIM on construction projects (see page 62) and a number of case studies.

To support CDBB's work to establish information management as "business as usual", a series of e-learning modules are being developed. There is already a range of BIM training and information available; the new CDBB e-learning resources will bring focus to the strategic deployment of BIM and the potential full asset life-cycle benefits that the process enables. The modules will provide a stepped engagement approach for selected subject areas, including: highlevel elevator-style pitches to engage senior decision-makers; mid-level "need-to-know-



to-deploy" information for those tasked with creating a corporate BIM environment; and guidance for those tasked with implementing BIM processes. The new modules are under development and will be available from the CDBB website in early 2019.

The CDBB BIM Level 2 team continues to work closely with industry bodies and communities of practice on joint communications and activities. To ensure industry is ready for the upcoming transition from UK standards to international standards for the information management using building information modelling, CDBB is working closely with the UK BIM Alliance and BSI to support industry through coordinated communications. To learn more about the transition, visit the dedicated page on the CDBB website.

"We are committed to a coordinated approach to creating and communicating an international wrapper for UK BIM and ensuring a smooth transition in the integration of BS EN ISO 19650-1 and 2 within our suite. Collectively we will develop and champion a single set of guidance in a clear and concise manner to support industry understanding and message how to make the shift without confusion."

UK BIM Alliance, BSI, CDBB





Home Nations Working Group

Harmonising BIM



David Philp Level 2 Communications Manager, CDBB

Ensuring that the benefits of effective information management are shared across England, Scotland, Wales and Northern Ireland is the remit of the Home Nations Working Group (HNWG). Formed in 2018, it brings together the four UK national BIM programmes to develop a consistent approach and to promote our vision of a digital built Britain. Growing capacity and embedding the UK standards for BIM remains central to the CDBB remit, and the HNWG has a pivotal role to play in this consolidation phase and in supporting the successful transition to international BIM standards.

The group has representation from all four of the UK's home nation BIM programmes, the Department for Business, Energy & Industrial Strategy (BEIS) and CDBB's international team. The HNWG provides a platform to:

- share experiences in the implementation • of the UK standards for BIM:
- coordinate the sharing of BIM knowledge and collateral across programmes;
- manage the interface between CDBB and the various devolved UK government BIM and digital built environment programmes.

Other key elements of BIM implementation looked at by the group include: shared practice around organisation information requirements (OIRs) and how it interfaces asset management activities and supports decisionmaking and implementing of PAS 1192-5:2015, a specification for applying appropriate and proportionate measures to holistically manage the security risks that affect a built asset and its data and information.

The group met several times in 2018, including in Edinburgh, Belfast and Cambridge, to share experiences, programme tools and portals and to agree a consistent definition of BIM Levels 1 and 2 along with supporting principles.

Creating a coherent and harmonised strategy also requires consistency of approach to the underpinning standards. At present the HNWG is focused on supporting the transition towards ISO 19650-1 and 2, Information Management Using Building Information Modelling, which is scheduled for publication in the UK in early 2019.

These new international standards will be accompanied by a UK National Annex and UK Transition Guidance. The National Annex clarifies country-specific usage and equivalent UK terms as opposed to those used in ISO 19650.

The UK Transition Guidance will be particularly important to the UK. It is aimed at the user, offering advice and guidance on applying the standard in the UK context, helping all those who have been using BS 1192:2007+A2:2016 and PAS 1192-2:2013, as part of their implementation of BIM Level 2, to transition to the new ISO standards BS EN ISO 19650-1 and BS EN ISO 19650-2. The transition guidance is not aimed at those who are brand new to this standard of information management but those already working in a BIM Level 2 environment.

The HNWG is conscious of the need for a smooth changeover to the new standard and has been working with the British Standards Institution (BSI) and the UK BIM Alliance to feed in their thinking to the UK National Annex and the related transition guidance. The group is also working on a coordinated transition communications plan, working alongside other stakeholders to help their programmes prepare for the changes that the ISO will bring.

Through the HNWG, CDBB is supporting a consistent approach to information management in public sector projects and procurement across the UK. This coordinated approach will ensure that all four nations grow together as a digital built Britain.

"The BIM Home Nations Working Group offers a collaborative forum to share and learn lessons in how government programmes are supporting the implementation of BIM. This supports members' strategic objective of increasing public sector BIM adoption that is aligned, considered and follows industry best practice."

> Paul Dodd, Associate Director Scottish Futures Trust Positive Impact Home Nations Working Group Member

Featured study

BIM Level 2 convergence report

The Level 2 Convergence programme is about defining and demonstrating the data pathways that will take us from the "BIM Level 2 world" of building more efficient assets to the "smart city world" of data-driven services that will improve the economic and social outcomes for UK citizens.

When developing CDBB's vision and strategy, it became clear that there is a big step – and a technology implementation gap – between information management improving how we design and build our infrastructure and how it enables the smart operation and performance of a portfolio of assets. And it is only by achieving the latter that we will fully realise the socio-economic promises of a digital built Britain.

Understanding how digital transformation and information management can improve how we operate and integrate our infrastructure will mean that different client groups (cities, asset owners and operators), the technology partners and the construction and asset management supply chains will need to work together in completely new ways. And this has significant implications for sharing data and standards across different sectors, such as energy, transport and health care.

In June 2018 CDBB asked digital construction specialists, Urban Innovation Labs, with extensive input from industry and academia, to set out the current standards landscape and its implications for the CDBB vision. The report is particularly concerned with how information is used and exchanged between

different stakeholders, in order to understand what information is critical if we are to link the outcomes and benefits for end-users back to the asset and built environment.

The standards landscape relating to all the sectors and industries that fall within the remit of the CDBB programme is vast. The Level 2 Convergence report considers whether the existing set of standards is capable of supporting that direct relationship between the beneficiaries of services and the planning, design and maintenance of the assets. One of the challenges it highlights is that the current standards are not designed to define service provision or to measure its socio-economic impact. This is something that will need to be addressed in the "operate and integrate" environment of a digital built Britain.

One of the ways the report suggests dealing with the complexity of the standards landscape is by creating meta-standards, or a "standard of standards". This may represent a breakthrough in establishing the connections and common language across different standards in different disciplines, from different perspectives and at different stages of the asset life cycle.

The L2C report makes a number of recommendations for next steps, including:

- The development of roadmaps for standardisation across sectors and, specifically, for the service-provision stage of an asset's life cycle.
- The creation of a capability within CDBB to understand how standardisation can be developed and used to drive market change.
- Supporting adoption through training, masterclasses, case studies and demonstrators.
- Testing and refining the meta standards methodology.

It also suggests that more research is needed on:

- The framework for defining service provision and its performance levels.
- Architectural frameworks for public services, from which the appropriate standards can be associated or developed.
- Methods for checking the compliance of standards, guidance, codes of practice and regulation.
- Understanding the ethical issues (such as trust and privacy) that will arise when standardisation supports new business and service models.



Read the report, Standards landscape and information management systems, in full at www.cdbb.cam.ac.uk

Featured study

What are the **Gemini Principles?**

As an industry we are beginning to understand that data needs to be valued, managed effectively and shared securely. We now need a common set of definitions and principles that can be adopted across the sector to underpin the development of the national digital twin. The Digital Framework Task Group is bringing together stakeholders from government, industry and academia to build a consensus on these definitions and values, which it has called the Gemini Principles.

The Gemini Principles report was published by the Centre for Digital Built Britain in December 2018 to begin enabling alignment on the approach to information management across the built environment, as establishing agreed definitions and principles from the outset will make it easier to share data in the future.

These principles are effectively the conscience of the information management framework and the national digital twin. To ensure that these two initiatives are – and remain – for the public good, they need strong founding values to guide them.

Enshrined in these values is the notion that all digital twins must have clear purpose, must be trustworthy and must function effectively. All the Gemini Principles flow from this. They are deliberately simple, but their implications are far-reaching and challenging. They are descriptive of intent, but agnostic on solutions, to encourage innovation and development over time.

The Gemini Principles will continue to evolve as the National Digital Twin evolves and we seek ongoing input into their development from across the sector.



"I welcome this seminal paper from the Digital Framework Task Group, bringing together key voices from government, academia and industry to build a consensus on the foundational definitions and guiding values needed to underpin this digital transformation. "

Richard Harrington MP Minister for Business and Industry Department for Business, Energy & Industrial Strategy

> Engage and join the conversation. Please share comments on the Gemini Principles: enquiries@cdbb.cam.ac.uk

The Definitions

Definition 1 **Digital twin**

A realistic digital representation of something physical.

Definition 2 **National digital twin**

An ecosystem of digital twins connected via securely shared data.

Definition 3

Information management framework

Enabling effective information management across the built environment.



Value creation Must facilitate value creation and performance improvement

Openness Must be as open as possible

Curation Must be clearly owned, governed and regulated

Insight

Must provide determinable insight into the built environment

Quality Must be built on data of an appropriate quality

Evolution Must be able to adapt as technology and society evolve

Chapter 2

Building the Research Programme



Introduction: **Dr Jennifer Schooling** Chair, CDBB Strategic Research Advisory Board Director, Centre for Smart Infrastructure & Construction

It has been a year since the Centre for Digital Built Britain was first launched. In that time, we have made substantial progress: we have started to define the research agenda, commissioned a diverse portfolio of research projects and embarked on the vital task of building an engaged and energised research community, drawing together the shared expertise of academics from across disciplines and UK institutions.

A multidisciplinary approach

It is the breadth of the task and the research questions we need to ask that makes developing the CDBB research agenda such an exciting and challenging proposition. If we are to understand fully how the buildings and infrastructure of the future are going to deliver better services to our citizens, we need to take a truly multidisciplinary approach.

We need engineers and architects to work with economists, linguists, social scientists, neuroscientists, psychologists, mathematicians and computer scientists – among others – to understand both the impact of the built environment on how we live our lives and how to design, build, operate and integrate assets that can deliver better outcomes for us all. "We need engineers and architects to work with economists, linguists, social scientists, neuroscientists, psychologists, mathematicians and computer scientists – among others – to understand both the impact of the built environment on how we live our lives and how to design, build, operate and integrate assets that can deliver better outcomes for us all."



Crossrail Tottenham Court Road station, western ticket hall deep box excavation. Ref: Adaptive design of supported excavations mini-project, by Dr Giovanna Biscontin, see page 36. Photo credit: Crossrail project and the contractor BFKJV C300-410 (BAM Nuttall, Ferrovial and Kier Joint Venture)

Progress to date

We started in January 2018 by commissioning 17 Cambridge "mini research projects" (see page 34) from across the University, including the Departments of Clinical Neurosciences, Applied Mathematics and Theoretical Physics, Engineering, Computer Science, Land Economy, the Faculties of Modern and Medieval Languages and Architecture and the Cambridge Clinical Movement Centre at Cambridge University Hospitals NHS Foundation Trust.

We have also made significant progress in defining the research agenda, which will enable us to develop the theories, practice and skills we need to make digital built Britain a reality. Our preliminary work was tested and refined in a series of workshops with colleagues from both industry and academia in April. From this activity emerged six research networks (see page 50) led by researchers from seven different UK universities involving an average of 28 UK institutions, and drawing on the contributions of over 450 academics.

A second call across UK academia has resulted in 17 further research projects, led from 9 different universities. Again, the projects draw from a wide range of academic disciplines addressing topics ranging from governance of digital technology in the city context through to aerial swarm robotics for bridge inspection and exploring the potential for blockchain in the construction supply chain.

Building the research community of the future

Ten of these most recent projects are led by early-career researchers. Creating a digital built Britain is not going to happen overnight. The research will need a cohort of dynamic and engaged academics who are now in the early stages of their careers to take it forward. Our research programme has been designed specifically to support these early-career researchers, encourage interaction between them so they can get a broader understanding of the challenges involved in building a digital built Britain and give them the opportunity to explore their leadership potential.

Next steps

We are in the process of collating the complete range of inputs and activities from our first year with a view to publishing, in the first quarter of 2019, a draft research agenda to support the journey to a digital built Britain. We have also carried out an initial mapping exercise for the research programme for the Construction Innovation Hub and look forward to developing that further in the New Year.

Finally, I would like to gratefully acknowledge the input of the Expert Group and of all the other reviewers and commentators, which has helped steer us in the early days of developing the research agenda and has continued to support us by reviewing proposals and outputs from our wide-ranging activities.

44 cross-disciplinary research projects and networks were awarded to institutions in these locations:

Mini-projects General research projects Salford Liverpool **Bristol** Cardiff



6

Featured case

Demonstrating the potential of digital twins

Research lead: Dr Ajith Parlikad

Project partners: Distributed Information and Automation Laboratory (DIAL) at the Institute for Manufacturing (IfM), Bentley Systems, Redbite, Topcon and GeoSLAM

A digital twin is simply a digital representation of a physical asset or a system. By providing real-time data about its condition and how it is being used, digital twins will have an important role to play in planning and managing our key assets.

Digital twin technology, therefore, promises much for the construction sector. Indeed, one of the key recommendations in the National Infrastructure Commission's 2017 report, Data for the Public Good, is the development of a digital twin of Britain's infrastructure, that will help us better plan, predict and understand our assets. CDBB is taking this forward and work is already well underway on developing the information management framework that will need to underpin the creation of a national digital twin.

In the meantime, there is still work to be done on developing the technology, which is in its relative infancy. To demonstrate its value for facilities management, productivity and well-being, CDBB funded a project to create a digital twin of the University of Cambridge's West Cambridge site.

The project aims to:

- show how digital twins can improve • organisational productivity;
- provide the foundation for integrating city-scale data to optimise city services such as power, waste and transport, and understand the impact on wider social and economic outcomes;
- help researchers to understand and address the major challenges in implementing digital technologies at scale.

The West Cambridge digital twin project has brought together researchers and a number of specialist companies to create a 3D digital model of the site using drone- and vehiclebased scanning and to create a register of its assets using an asset-tagging system.

Digital twin technology relies on being able to integrate data from different data sources to enable effective data analytics and drive better decisions. In order to achieve this, the team is investigating ways to integrate the asset data with the 3D BIM model, ensuring that the digital twin adheres to common data standards and is interoperable. Using open standards is an important aspect of this project for two reasons. As well as helping to make sure that the digital twin development is vendor-agnostic, it is also a useful way of revealing any gaps and weaknesses in the current open source schema.

The project is also exploring potential applications for the digital twin.

These include:

- Better asset maintenance using predictive data analytics;
- Better asset tracking;
- More efficient use and management of equipment;
- Finding ways to reduce energy consumption;
- Using augmented reality to help with maintenance and inspection.

"Our work with Ajith and the other companies on this project has been an important digital twin test bed for Bentley. We have specifically valued connecting real-world challenges with research leaders and the demonstration and understanding of the impact that digital modelling can make in our business"



David Robertson, Director, Digital Advancement Research, Bentley Systems

IfM Digital Twin

Featured study

Platform approach to design for manufacture and assembly:

Bridging the gap between construction and manufacturing



Research lead: Jaimie Johnston - Bryden Wood, The Manufacturing and Technology Centre (MTC), CDBB

The "off-site revolution" in the construction sector has been talked about for many years without much progress. However, there are a number of reasons to support the view that we are now on the cusp of significant change. The sector is facing well-rehearsed challenges in relation to costs, labour, productivity and the fragmented nature of its supply chain. Globally, we need to find a way of building homes for an urban population that is likely to increase by 2.5 billion by 2050. At the same time, the uptake of BIM means that the digital tools needed to support a manufacturing-led approach are being put in place.

In March 2018 Bryden Wood Technology Ltd published a report for CDBB setting out the benefits of a manufacture-led approach to construction and showing how it would support the commitments made by the UK government to improving the construction sector. In particular, it looked at ways in which the construction sector could learn lessons from the manufacturing, automotive and software industries and create significant value by doing so. Platforms have been critical

to the development of both of these industries, allowing them to scale and innovate while reducing costs through increased efficiency.

The report, Delivery Platforms for government Assets: Creating a Marketplace for Manufactured Spaces, explains how the construction sector could borrow this platform approach to design for manufacture and assembly, or P-DfMA, to achieve a much more efficient and scalable approach to physical construction. In construction, most buildings relate to the human form. This means that dimensions such as ceiling heights or distance from a window fall within predictable ranges, which can be used to define a small number of platforms that can accommodate a wide range of needs, from a bedroom to a sports hall. Within those platforms, connections and interfaces can be standardised so that just a few designs meet a huge range of needs, and many components are repeatable. The report found that on projects for the Ministry of Justice it's possible to construct almost all of the complex estates using a combination of just three platforms.

P-DfMA is typified by "continual improvement" - the components are improved or expanded over time by incorporating lessons learnt and innovations in materials science and manufacturing processes. This is very different to the "constant reinvention" of traditional construction where there is a lack of standardisation and components tend to be designed from first principles for every new asset.

What is a P-DfMA?

P-DfMA provides the ability to adopt "mass customisation", combining the flexibility and personalisation of custommade products with the low-unit costs associated with mass production. For example, a single component could be used as part of a school, hospital, prison building or station, minimising the need to design bespoke components for different types of commonly built asset. Construction platforms would be made from components (products or sub-assemblies manufactured by a range of suppliers), with known interfaces, that could be combined in a consistent and well-defined way to create highperforming assets.

Driving P-DfMA through government procurement

In November 2018 the government published details of a proposal for a preferred approach to building infrastructure using P-DfMA, where it presents value for money. Results from this call for evidence will feed into the development of the P-DfMA strategy for government, to be led by the Infrastructure and Projects Authority (IPA) and the Department for Business, Energy & Industrial Strategy (BEIS). Through the Core Innovation Hub, CDBB, as part of the Transforming Construction Alliance, will support pilot P-DfMA construction projects in government departments.



Funded research projects

Summaries of the 17 mini-projects funded by CDBB between March and July 2018. These multi-disciplinary research projects explored the breath of the Centre's mission "to develop and demonstrate policy and practical insights that will enable the exploitation of new and emerging technologies, data and analytics to enhance the natural and built environment, thereby driving up commercial competitiveness and productivity, as well as citizen quality of life and well-being". Full reports, video summaries and papers from the research projects are available CDBB website.



Artist impression of Cavendish 3 - due for completion 2022 - used as a case study by Thayla Zomer, see page 70 for more information. Image courtesy of Jestico + Whiles Architects

The Edge: A case study and template for BIM Level 2

Researchers:

Dr Aftab Jalia

Department of Architecture, Centre for Natural Material Innovation, University of Cambridge **Dr Michael Ramage** Department of Architecture, University of Cambridge Ron Bakker - PLP Architecture

The Edge is an office building in Amsterdam that showcases the benefits of BIM. Completed in 2014, and widely regarded as the smartest and most connected office building in the world, it was built with the Internet of Things (IoT) as its guiding principle.

Cognisant of the benefits of a digitally integrated design and construction ecosystem, the building employed an exemplary use of smart technologies that demonstrates a BIM-enabled future. Today, nearly 28,000 sensors continuously feed data generated by users into a "data lake" which allows its operational teams to monitor in extraordinary detail how the building is being used, its energy performance and maintenance issues.

However, the lessons we can learn from The Edge are not just about the impact of cuttingedge technologies. The success of the project was the result of effective communication between the key stakeholders - the client, the architects, the real estate company and three technology firms - all of whom championed innovation and worked together to deliver it. As well as using The Edge as an example of what can be achieved through BIM, this research project looks at the "human" factors that made it possible: having all the key participants working on "the same side of the table".

Designing safe complex environments

Researchers:

Dr Thomas Stone

Cambridge University Hospital, Clinical Movement Laboratory University of East Anglia, School of Health Sciences Dr Adar Pelah - University of York, **Professor Manohar Bance** Department of Neurosciences, University of Cambridge

We know that today's built environment often fails to meet the needs of people with functional limitations. This project explored the possibilities of using virtual reality (VR) to support the design of safer built environments for people with complex sensory impairments. Recent neuro-architectural research indicates that people respond in exactly the same way regardless of whether they are in a real or virtual environment. This, in turn, suggests that VR could indeed have an important role to play in designing more inclusive buildings and public spaces by allowing designers to create and test environments for different users before committing to expensive prototypes.

The researchers combined low-cost VR hardware and motion-sensor software to create a complex environment for a user to walk in. The system was successfully tested with five unimpaired subjects. The next step is for the researchers to get Health Research Authority (HRA) approval to trial this promising technology with real patients.

Urban planning and BIM

Adaptive design of supported excavations

Researchers:

Professor Phil Allmendinger School of the Humanities and Social Sciences, University of Cambridge Dr Franziska Sielker Department of Land Economy, University of Cambridge

Although we are making good progress towards the goal of BIM becoming "business as usual", there is still significant work to be done in relation to the UK's planning system. This research project explored the relationship between BIM and planning and found that awareness of BIM within the planning system is currently low to non-existent in spite of both a local and national commitment to the development of digital infrastructure and "smart cities".

A clearer understanding of – and support for – BIM throughout the planning system can help national planning policy achieve some of its key objectives, such as reducing costs and waste, creating more sustainable development and delivering better services to its citizens. At the same time, the planning system has a vital role to play in delivering BIM and the wider digital built Britain objectives, both by engaging communities and end-users and by using its processes and regulatory mechanisms to put BIM into practice.

The report's principal recommendation is that the government should publish national policy on BIM and planning to help align their objectives and to ensure that local planning understands the needs and benefits of BIM. As well as raising awareness it would require local authorities to consider BIM when preparing local plans and taking decisions on development proposals.

Researchers: Dr Giovanna Biscontin Department of Engineering, University of Cambridge Yingyan Jin Department of Engineering,

Geotechnical engineering is concerned with how the earth you are building on – or in – is likely to behave during construction. Although techniques for making predictions about, for example, ground movements have improved in recent years it is still impossible to predict exactly what will happen once you start building.

University of Cambridge

In most projects, the excavation is planned and finalised before construction starts. To deal with the uncertainty, engineers typically take one of two approaches: they either build in excessive safety measures or they make assumptions based on past experience. The former is expensive and the latter potentially unsafe. There is a third approach, known as the observational method (OM), in which engineers make a preliminary design based on the available knowledge, which is then monitored and modified as necessary throughout the construction process. Although this approach saves time and money while maintaining high safety levels, it is difficult to implement.

This research project shows that by using advanced real-time analysis tools on the large amount of data that is now available during construction, OM becomes a more viable option. The report also makes a number of recommendations for supporting the takeup of OM, including the publication of case studies, guidelines, good practice around data collection and the development of visualisation tools that can combine realtime data with automated back analysis and present it in a more intuitive way to help engineers with their decision-making.

Opportunities and barriers to adoption

The uptake of digital tools, standards and processes in innovation in the UK house building industry

Researcher:

Dr Gemma Burgess Cambridge Centre for Housing and Planning Research, Department of Land Economy, University of Cambridge

The UK's housing crisis demands innovative and affordable models of housing production and design.

Within the industry there is a recognition that BIM has an important role to play, helping to speed up construction while reducing costs, design clashes, costly reworking on site and the number of defects in new homes.

However, the take-up of BIM remains low amongst house builders. For the main house-building companies, adopting BIM takes considerable investment of time and resources at a time when the industry is at the upward part of a building cycle and working at capacity. There are also skills shortages, both for house builders and their numerous suppliers. Some progress has been made in encouraging suppliers to make greater use of BIM, but the nature of the industry, with many small sub-contractors over multiple sites, has meant that downstream adoption has been more problematic.

This report recommends that there needs to be a raising of awareness of what BIM is, how it can be used and the benefits it can offer within the house building sector. This may need to come from different sources and will need to be both top-down and bottomup. Specific guidance about the use of BIM, tailored to the house-building industry, may be needed, along with training and the inclusion of BIM in college courses to embed it in the learning of the next generation in the industry.

Building interactive smart acoustics into buildings and clothing

Researchers:

Dr Anurag Agarwal Department of Engineering, University of Cambridge Professor Manohar Bance Department of Clinical Neurosciences, University of Cambridge

The UK population is ageing rapidly. Hearing loss is epidemic among older adults, with more than 70% of people over 70 having hearing loss. Many of them wear hearing aids that are "smart" and can "beam form" to pick up sounds in one direction. However, the one or two microphones that can fit on a small hearing aid are not able to fully characterise the complexity of the acoustic environment. Hearing aids are also unable to measure reverberation and other complex aspects of the acoustic field.

This project proposes putting multiple "hearing" sensors (or microphones) into wearable technologies. These sensors could also talk to other microphones placed in the building's walls. With appropriate signal analysis, this could significantly improve the effectiveness of hearing systems. The wearable sensors could also produce an acoustic signal intermittently to measure the reverberation of the acoustic environment and adjust for it.

As well as helping people to hear better, this technology could also help us to understand and improve our acoustic environments more generally. It could also replace FM systems that plug into hearing aids for hearing impaired children in schools.

This first part of the project is to create a flexible, wearable acoustic sensing system that can be incorporated into clothing.

Autonomous image recapture

Researchers:

Dr Michael Ramage Department of Architecture, University of Cambridge Professor Joan Lasenby Department of Engineering, University of Cambridge Hugo Hadfield Department of Engineering, University of Cambridge Dr Chris Doran ARM, Cambridge

Understanding how cities and infrastructure have changed over time is an important aspect of both historical research and future planning but doing so accurately and in detail is not straightforward.

This research project used advanced image processing and computer vision techniques to recreate geospatial viewpoints used in a series of line drawings of Cambridge colleges by seventeenth-century engraver, David Loggan. Drone flights were used to capture images of the same colleges from the same viewpoints. The researchers then overlaid the images and the drawings, highlighting their differences and similarities. This leads to interesting questions in the field of history-of-architecture and, potentially, to a new way of carrying out detailed structural and architectural analysis of historical buildings. In addition, the researchers have shown that the automatic inclusion of lines (as well as points) in the extraction of 3D data from drone footage can improve camera localisation and lead to more accurate reconstructions.



Autonomous image recapture of Clare College; Drawing by David Loggan / Photo by Michael Ramage

Exploiting traffic data to improve asset management and citizen quality of life

Researchers:

Adrià Salvador Palau Dr Ajith Kumar Parlikad

Department of Engineering, University of Cambridge Jon Roozenbeek Faculty of Modern and Medieval Languages, University of Cambridge

Effective traffic management and highway maintenance are critical to our economic, social and cultural well-being. "Criticality analysis" is a useful way of helping us to understand which roads or other transportation services are most important for maintaining access to, say, a hospital. It can also inform decisions regarding investment planning, maintenance prioritisation and monitoring. However, carrying out an accurate criticality analysis in this context is often hampered by the availability of good-quality information. This project addresses this key issue by making use of a global data source: Google Maps and its API.

Using the Google Maps API the researchers successfully analysed the accessibility of Cambridge University's new research centres; the criticality of roads leading to Addenbrooke's Hospital in Cambridge; and the accessibility of some critical assets in Hertfordshire. They also addressed the challenges facing some Cambridge commuters.

The approach could have a useful role to play in helping both the private and public sector better manage transportation and access to their services.

Future cities and BIM

Researchers:

Dr Franziska Sielker Department of Land Economy, University of Cambridge Professor Phil Allmendinger School of the Humanities and Social Sciences, University of Cambridge

More than half of the world's population now live in cities and this is only set to increase. We urgently need more housing and infrastructure while recognising the need for low-carbon solutions and energy-efficient buildings. BIM has a key role to play in the development of both smart and sustainable cities but this study found that local planners and stakeholders are often not aware of BIM and are a very long way from having a vision of a BIM-supported city development.

However, the research suggests that BIM can benefit from the gathering momentum of smart cities strategies. The opportunity to link data from BIM-modelled construction sites to a wider city development has already been captured by the concept of CIM.

BIM and CIM can both be understood as enablers for smart city development. CIM can take smart city development to the next level, and integrate the information provided by BIM into city planning and development. Recognition of the importance of BIM at the urban level does, however, need to be recognised in national strategies through, for example, planning provisions, the support of e-planning and education.

More research is needed to explore how national strategies can help local planning systems to integrate BIM and collaborate more effectively with the construction industry.

Current practice and future research

Ancillary sensing for building information modelling

Researchers:

Dr Mohamed Zaki

Cambridge Service Alliance, Department of Engineering, University of Cambridge **Dr Ben Lucas** Nottingham University Business School

Capitalising on new digital data sources is central to the development of BIM and the progress of the construction sector as a whole. If we are to move beyond BIM Level 2 towards the CDBB Design, Build, Operate, Integrate model, our reliance on data will become even more critical as we start to use it to better understand user needs and behaviours and turn them into asset- and system-performance measures.

This project looked at two important but under-investigated areas. First, how much is user-generated online data – such as social media – currently informing the design, creation and management of the built environment? Secondly, what is the potential impact of advances in occupier behaviour modelling using new human-focused sensor technologies and computer vision?

The report is intended for researchers and practitioners looking at how sensor-enabled human behaviour research can affect the design of physical spaces. The researchers pointed to a number of areas for future research to help us understand what kinds of spaces are most conducive to well-being, encourage quality interaction between the occupants, foster positive organisational cultures and employee engagement, and support creativity and innovation.

Crowdsourcing data in mining spatial urban activities

Researchers:

Dr Elisabete Silva Haifeng Niu

Department of Land Economy, University of Cambridge

Crowdsourcing gives us access to new data sets for analysing the urban environment, telling us both where people congregate and why. The aim of this project was to develop a methodology for data harvesting and data mining to investigate the different causes of urban segregation.

This project was piloted in Cambridge and then compared with a prior study of Ningbo in China in order to synchronise and validate the data-collection methods across the two case studies.

The pilot looked at how data from social media is distributed around Cambridge (by geo-tagging tweets) and what that revealed about spatial segmentation and its relationship with the built environment. It also looked at how to validate and enrich the data using other sources such as questionnaires to make sure that no important social groups were excluded from the analysis because they don't own or use the devices producing such data.

The pilot demonstrated that crowdsourcing data can be an effective resource when used in conjunction with other socio-economic spatial data. It also provides a conceptual and methodological framework for analysing crowdsourcing data.

Feasibility of an operating system for interspatial networking in a built environment

Researchers:

Dr Anil Madhavapeddy Gemma Gordon KC Sivaramakrishnan

Computer Laboratory, University of Cambridge

Today's digital infrastructure tends to rely on the Internet and involves transmitting data to physically remote environments. This results in data insecurity, slow response times for interactive services and unreliable services. A future in which sensors are connecting millions of buildings worldwide cannot be realised unless we develop a new type of infrastructure.

The research team has designed a new operating system – Osmose – which provides ground-up services for connected devices in a building. It aims to connect physical spaces securely with very responsive, high-bandwidth local-area computation capabilities and service discovery.

Osmose is able to run applications across the hundreds of embedded devices that form a modern environment, such as environmental sensors, audio and video capture, and also support a new generation of directed sensorial generators. It runs with no external connectivity, with all the resources required for machine learning and storage provided by local processing units.

Having achieved promising early results, the researchers are now starting to deploy a real prototype at Pembrooke College. The operating system forms part of the LABScl Imagine project with Stanford University which aims to provide a virtual reality field trip program for students unable to experience nature firsthand.



VR Data collection as part of the LABScI Imagine project, photo courtesy of Dr Anil Madhavapeddy

IoT network behaviours and dependencies

Researchers: Dr Richard Mortier Dr Poonam Yadav Oi Li

Department of Computer Science & Technology, University of Cambridge

Realising the vision of a digital built Britain will require the creation and use of many sources of digital data, particularly as we move beyond BIM Level 2 to the Operate and Integrate model. There is a widely held perception that much of this data will be created by using off-the-shelf Internet-of-things (IoT) sensors in buildings and infrastructure at scale. In this study the researchers began to look at the implications of this by looking at some baseline data gathered from a set of such sensors.

They considered a wide range of sensors from those recording environmental conditions such as temperature or CO2 levels to some more obviously sensitive sensors, such as video cameras. The researchers observed a number of issues:

- Little use is being made of "standard" IoT protocols, with most traffic using the HTTPS web protocol and all devices making use of standard Internet control protocols.
- Device updates appear to take place during the early hours of the morning, relying on network connectivity between 3.00 and 4.30 am, currently a "quiet time" for most ISPs and one during which some proportion of households may still turn off their home broadband.
- Even in this small sample, some devices exhibit quite pathological behaviour.
- And most exhibited dependencies on services run by other companies in other countries, indicating that there is a complex "digital supply chain" in play.

The report recommends that more detailed analysis clearly needs to be done, on an ongoing basis and across a much wider range of devices.

Building impulse: a novel digital toolkit for productive, healthy and resource-efficient buildings

Researchers:

Dr Mauro Overend Dr John Orr Professor Tim Ibell Dr James Talbot Alessandra Luna Navarro Mark Allen

Department of Engineering, University of Cambridge **Alistair Law** - Arup

By 2050 it is estimated that cities will need to cater for an additional 2.5 billion inhabitants. These cities will need resource-efficient, healthy and productive buildings that can mitigate the impact of climate change. One of the ways this can be achieved is by harnessing new technologies to make buildings more adaptable and responsive to changing conditions. This could include things like switchable glass that can change its opacity depending on temperature and light levels. However, one of the barriers to implementing these dynamic technologies is that it is difficu to capture users' responses to them when their environment is changing all the time.

To address this challenge, this research team created a building impulse toolkit (BIT), a novel array of digital sensors and other methods for capturing overall occupant response in terms of comfort, satisfaction, productivity and well-being.

	BIT will provide a way of establishing quantitative relationships between changes
	to environmental characteristics and overall
	occupant satisfaction and productivity.
f	The toolkit combines three elements:
9	environmental monitoring, unobtrusive
	systems for continuous occupant feedback
	and indirect systems for capturing occupant
	preferences. The first prototypes are to be
	tested in offices in London and in a new
	office-like test facility, called MATELab (Mobile
	Adaptive Technology Experimental Lab) at the
lt	University of Cambridge.

Researchers:

Machine learning and AI in the built environment

Dr Thies Lindenthal Land Economy, Department of Economics, University of Cambridge Dr Erik B. Johnson Department of Economics, University of Alabama

Transactions for residential properties are readily available public data in the UK, making it relatively easy to analyse some aspects of the built environment from an economic perspective. However, the level of detail for each transaction is very low. By combining big data with advances in machine learning (ML) it is possible to enhance this sales data using a variety of other data sources.

ML can help us better understand our built environment by classifying the different types of building and infrastructure that it contains. While the cost of developing ML systems has fallen dramatically in recent years, there are still significant barriers to its adoption. ML systems need "training data" to learn from. Collecting this data remains complex and costly. Using a trained model for inference at a large scale, soliciting feedback on model predictions and managing the flow of expert feedback into new iterations of the model are also difficult processes to manage.



Distribution graph of residential similarity derived from remotely sensed building models. Photo credit Dr Thies Lindenthal

Visualising the future: big data and the built environment professor

Researchers:

Professor Paul Linden Dr Rosamunde Almond Simon Patterson

Department of Applied Mathematics and Theoretical Physics, University of Cambridge

PolyChora Alpha: a new digital interface for interdisciplinary city design

Researchers: Dr

Dr Ying Jin

The Cities and Transport Research Group at the Martin Centre for Architectural and Urban Studies, Department of Architecture, University of Cambridge

This report explores the future role of big data in the built environment. It captures insights from researchers, government officials and industrialists who took part in the Cambridge Forum for Sustainability and Environment, supplemented by a series of semi-structured interviews with key individuals.

The report considers how different sectors face different barriers to using big data within the built environment. These include budgetary pressure, resource allocation, technical challenges resulting from legacy systems, crossing organisational boundaries (even within connected public sector entities), data access and privacy concerns at an individual level. It explores the need for regulation, either formally through legal structures or through the evolution of social norms, while recognising the challenge of regulating a rapidly developing area of technology. Related to all these points is the key challenge of engaging people who live and work in cities.

The report suggests that while big data is clearly not a panacea, it can support the optimisation of systems and the identification of, as yet unknown, patterns. This is particularly important for understanding cities, where innovation and growth are bringing about rapid change. The ability to respond to changing circumstances as a result of realtime analytics will enable far more efficient resource allocation and supply and demand monitoring in cities both now and in the future. In the past decade, a variety of data analytics and modelling techniques have been used in the planning and design of buildings and infrastructure. While BIM and associated standards are being implemented within each of these areas, there is still a lack of connections and interface between these data sets. This has hampered progress in co-design and coordination among the design disciplines, especially in fast-growing cities where it is essential to join up the planning of business premises, housing and transport in the design of specific buildings or infrastructure.

This research team has pioneered a new way of connecting data and modelling among economists, transport and traffic engineers, housing and neighbourhood planners, urban designers and infrastructure investors in their integrated computer models of cities. Its models have already been used around the world to predict the combined effects of planning, design and infrastructure interventions.



design for manufacture and assembly demonstrated at Working Together: Transforming n Event, The Manufacturing Technology Centre (MTC), March 2018. See page 32 for more.

Funded research networks

CDBB is funding six research networks that will bring together academics from different institutions and disciplines to define the research agenda that will take us towards a digital built Britain. A full report on the findings of the networks will be published by the Centre in early 2019.

- 200+ individuals were involved in network workshops
- In total 350+ attendees at networks workshops
- A total of 450+ people involved • in contributing to the work of the networks



Vision network: augmented reality and virtual reality for digital built Britain

Research lead: Dr Manuel Davila Delgado UWE Bristol

Augmented reality (AR) and virtual reality (VR) technologies are already widely used for gaming and entertainment, tourism, marketing and for education and training. They also have the potential to play a critical role in architecture, construction and engineering, all of which rely on imagery for communication. In its 2017 report, Data for the Public Good, the National Infrastructure Commission considered AR and VR to be key to increasing the productivity of infrastructure

So far there has been no meaningful attempt and in supporting decision-making. These to digitise regulations/requirements or technologies will be essential when visualising compliance systems. The state of the art in the data in real-time - as well as in context - to field is currently represented by the limited deliver smart cities and smart infrastructure. compliance checking done by software The Vision Network will explore AR and VR's vendors, along with the development of a role in enhancing the level of performance number of ad hoc approaches to monitoring and achieving compliance across varying and digitisation for smart cities and smart construction at citizen, portfolio, organisation stages of the construction life cycle. These ad hoc solutions have many limitations. and project levels. It will do so by looking at They are not able to scale from small to larger its role in the design, delivery, operation and integration phases and its impact on different buildings or to district/city levels, they cannot stakeholders such as owners, builders, be adjusted to support different requirements, or to translate from one project to another and managers and users. they often need significant technical expertise to implement. This lack of satisfactory solutions is compounded by the fact that much of this area remains sparsely researched, particularly the concept of a "living brief" with requirements spanning the entire life cycle of the asset, technologies to enable site-based monitoring of compliance and monitoring of compliance of assets once they move into the operation phase of their life cycle after handover.

D-COM: digitisation of requirements, regulations and compliance checking processes in the built environment

Research lead: Dr Tom Beach Cardiff University

The entire life cycle of the built environment is governed by a variety of regulations and requirements. These range from contractual requirements, requirements specified in the project brief, legislative requirements and self-imposed environmental performance requirements. Checking compliance against all these requirements is a complex task and, because it is performed manually, a highly resource-intensive one.

The D-COM Network has been formed to drive forward the adoption of the digitisation of regulations, requirements and compliance checking systems in the built environment.

Pedagogy and upskilling

Methodologies for planning complex infrastructure under uncertainty

Research lead: Professor Jason Underwood University of Salford

Research lead: Dr Chris Dent University of Edinburgh and Alan Turing Institute

To deliver a digital built Britain the UK needs a digitally-enabled, agile, competent and productive workforce. This network is looking at how we are going to achieve that through the proposition for the need "to define a robust, sustainable and collaborative competency management approach to lifelong learning of individuals, organisations, and other stakeholders within the competency demand and supply ecosystems to facilitate the digital transformation to deliver digital built Britain".

Implicit to this proposition is that education, learning, upskilling/re-skilling, training, and professional competency development are a lifelong process that requires many interactions across the life of individuals, organisations, and ecosystems, which all must be set in the context of competencybased evolution. Key to this is how we upskill a workforce against a moving target, whereby work, the ways of conducting work, and the competences required are rapidly changing or re-configuring.

The generalised career paths and traditional training interventions (i.e. old "route" map) are no longer relevant or effective and therefore a more dynamic, granular, personalised etc. infrastructural approach is required, i.e. ecosystem of competency management and analytics.

Infrastructure assets are typically capitalintensive investments with long lifetimes - they can be single "mega-projects" or they require resource allocation across multiple options for smaller projects.

Mega-projects have a number of challenges. They tend to have both public and private stakeholders and take years to develop and build, which adds to their complexity and uncertainty. The investment decisions therefore have to be made under great uncertainty over the future planning horizon.

This Network will take an interdisciplinary approach to understanding:

- The state-of-the-art in how modelling is used to support infrastructure planning decision-making, both in industry and policy practice, and in the research community;
- The needs of the practitioner community for research and innovation on methodology;
- Which research communities need to be engaged to achieve this and which methodologies we should adopt to address the challenges identified by practitioners.

Network FOuNTAIN: Network for ONTologies and Information maNagement in digital built Britain

Research lead: Dr Peter Demian Loughborough University

With the establishment of concepts such as building information modelling (BIM) and common data environments (CDE), built environment design, construction and operation are becoming increasingly information-intensive.

For stakeholders, trying to meet their information needs is increasingly like finding the proverbial "needle in a haystack". That can be even more challenging if one is unaware that one is looking for a needle, one is unfamiliar with how the haystack is structured or it is not structured at all.

The Network will simultaneously consider the following three dimensions:

- 1. the life cycle of information, from its creation, delivery, capture, preservation, management, automation, retrieval and reuse;
- the whole and extended asset life cycle 2. from concept design, through operation, to service delivery and use;
- 3. increasing asset scale ranging from a single asset to an entire neighbourhood or city.

The Network FOuNTAIN's vision is for all stakeholders in digital built Britain to be able to meet their information needs.

Housing digital built Britain

Research lead: Dr Gemma Burgess University of Cambridge

Housing sits at the heart of many wider social issues, and it will sit at the heart of the development of a digital built Britain (dbB). The Housing Digital Built Britain Network will focus its attention on residential housing: delivering a digital built Britain is not simply about technological solutions to make supply and maintenance more efficient – although this is important – but it is also about understanding how those solutions and efficiency gains interact with wider social policy issues to address the inequalities in the UK.

The Housing Digital Built Britain Network will bring together academics, practitioners, policy-makers and government to facilitate dialogue and determine the key areas of inquiry in relation to residential housing and dbB. Working with these partners, the Cambridge Centre for Housing and Planning Research will determine the priority issues for investigation, mapping them onto the CDBB framework and developing position papers that will form the key areas of focus for our research. The aim is to scope out a research programme to meet the needs of UK plc in delivering affordable, sustainable and inclusive housing in a digital built Britain.

"Creating a digital built Britain is not going to happen overnight. The research will need a cohort of dynamic and engaged academics who are now in the early stages of their careers to take it forward. "

> Dr Jennifer Schooling Chair, CDBB Strategic Research Advisory Board, Director, Centre for Smart Infrastructure & Construction

Recently awarded research projects

CDBB recently awarded funding throughout the UK for seven general research projects and to ten early-career researchers (ECR). The funding is for research aligned to the Centre's mission "to develop and demonstrate policy and practical insights that will enable the exploitation of new and emerging technologies, data and analytics to enhance the natural and built environment, thereby driving up commercial competitiveness and productivity, as well as citizen quality of life and well-being". Full reports and papers from the research projects will be available CDBB website in Summer 2019.

General projects

Dr Jan Boehm - Open ML training data for visual tagging of construction-specific objects (Con Tag)

Dr Ruchi Choudhary - Energy planning for resilient decarbonization

Professor Claudia Eckert - Immediate (Integrated Management of Margins through Evaluation, Design, Analysis, Tracking and Negotiation)

Dr Ying Jin - Digital modelling of the evolution of the built form in Britain

Dr Ges Rosenberg - Co-creating a city-scale digital strategy and framework: a systems and co-production approach

Professor Patricia Tzortzopoulos -

Recommendations for automated checking of regulations and requirements management in healthcare design

Professor Jennifer Whyte - Analysing Systems Interdependencies using a Digital Twin



ECR projects

Dr Isolda Agustí Juan - From Norm to Swarm: development of a balanced scorecard for evaluating automation in construction

Dr Zaid Alwan - Digital Energy Estimation Tool (DEET)

Dr Karen Blay - Information Resilience – exploring ways to leverage data and information to deliver a digital built Britain

Dr Shan Luo - Aerial swarm robotics for active inspection of bridges

Kathryn Muir - Explore the use, uptake and barriers of digital technology in shared housing

Dr Timea Nochta - The local governance of digital technology – implications for the city-scale digital twin

Dr Amanda Prorok - Evolving Built Environments and Mobile Autonomy for Future Transport and Mobility

Dr Franziska Sielker - Future Cities in the making – overcoming barriers to information modelling in socially responsible cities

Dr Algan Tezel - Toward Blockchain – enabled construction supply chains: Potential, requirements and implementation

Dr Li Wan - A digital twin prototype for journeys to work in Cambridge

Chapter 3

Supporting Change



Introduction:

Alexandra Bolton Deputy Director, CDBB

No one should underestimate the size of the task we have set ourselves. To create a digital built Britain will take a huge amount of change across an industry in which most firms employ fewer than seven people. How are we going to do it? And what is CDBB's role in making it happen?

First and foremost, change on this scale can only happen if government, academia and industry work together towards a shared vision of a digital built Britain. Building a consensus around that vision and demonstrating its value to everyone in the sector – for the smallest firms, as well as the largest – are, therefore, a vital part of what we are doing. We are not simply painting a picture of an exciting destination. With our partners, we are working to define the steps that lead to that destination and to provide practical support along the way.

Managing information effectively

None of this can happen without good data. The promotion and adoption of the UK's standards for information management and digital transformation are, therefore, central to our role. And we are making encouraging progress in this regard. At the end of 2018, the first output of the Digital Framework Task Group was published - the Gemini Principles. CDBB has requested input into the "conscience" of the national digital twin and is also working to produce a roadmap for the information management framework.

The government's BIM mandate in 2016 provided a huge impetus for change and has encouraged many companies to embark on their digital journey. We have, for example established a successful series of BIM Level 2 roundtables with the Chartered Institute of Building to help its members continue their progress towards BIM Level 2 and effective information management as business as usual. We have commissioned PwC to develop methodologies that will help organisations better understand and quantify the benefits of BIM. And (see page 62) we are developing e-learning modules that will help firms put BIM into practice.

Addressing the security challenges

As our reliance on data increases, so does our need for security. This is also a key focus for CDBB (see page 68) and an area in which we are actively developing support for industry. At a recent CDBB event, users and providers of smart infrastructure solutions heard from leading UK experts on how to take a securityminded approach to digitalisation. CDBB's security project manager (and technical lead on PAS 1192-5 and PAS 185 security standards), Alexandra Luck, led a workshop in which delegates were able to learn from one another's experience of adopting security practices.

Seizing our international opportunities

The data revolution is at the forefront of the government's Industrial Strategy Grand Challenges, providing a huge opportunity for the UK's construction industry. CDBB's international programme has been expanding rapidly in response to demand from countries seeking our services and expertise (see page 64). We are already working with more than 30 countries around the world to implement UK methodologies for infrastructure development and, by doing so, we are actively creating commercial opportunities for UK construction firms and service providers.

This activity was further bolstered in June by the launch of the UK government's Global Infrastructure Programme to improve infrastructure in middle-income countries. Three countries – Columbia, Vietnam and Indonesia – have already signed a Memorandum of Understanding with the UK government and CDBB is providing them with expertise on digital construction methodologies, training and workshops, and supporting the procurement exercise required for projects in the partner countries.

Making change happen

A digital built Britain has the potential to transform the way we live our lives while contributing to our economic prosperity. To make it happen, we need strong direction and engagement from the government and new ideas, technologies and training from our universities. But, ultimately, the change itself has to take place in, and be led by, industry.

A year of engagement in numbers

350+ Attendees at CDBB events, including Summer Showcase and Security Mindedness

1500+

Followers and 700+ mentions on Twitter and a growing LinkedIn network

800+

Subscribers to the CDBB newsletter

Papers in the

CDBB publication series

45 Thought leadership blogs on the CDBB website

At CDBB, our job is to listen to industry, to understand its needs and challenges and, by informing and coordinating government and academic initiatives, to build the evidence base and the mechanisms that will bring about the change.



Networking at the CDBB Summer Showcase July 2018

During 2018-19 the Centre for Digital Built Britain (CDBB) and the Chartered Institute of Building (CIOB) have teamed up for a programme of high-level "roundtable" discussions, which aim to further accelerate adoption of the government's digital strategy for the built environment, especially the successful embedment of BIM Level 2 across industry. Involving significant industry and government figures, the debates will help inform the future direction of the programme. An output at the end of the roundtable programme creates practical continuous professional development (CPD) material.

"The roundtables will help identify challenges to BIM Level 2 adoption faced by industry, and help to shape Centre outputs and recommendations."

David Philp of the CDBB team



Participants at the CDBB/CIOB roundtable event on 28 November, COIB, London

Ensure that findings and insights from the Centre and its engagement activities inform future policy, industrial practice, standards and research initiatives.

Develop, inspire and coordinate an industrial community via working groups who, combined with academics and policy leaders, will provide leadership on adopting and implementing new digital approaches.

cordi

Coordinate and deliver a range of events and activities designed to engage industry in defining and adopting effective information management and digital transformation for operation and integration of assets.

Engage

Supporting adoption and implementation by industry

Liaise with national and international standard bodies to create and modify technical standards and protocols.

that the digital built Britain programme undertakes research and incorporates technological developments.

Centre for Digital Built Britain

Track capabilities in the UK and elsewhere to ensure successful commercial exploitation of these new technological developments, identifying where capability investment may be required.

Featured study

Understanding and measuring outcomes right from the start

Information management using BIM takes a multi-level approach: organisations must set out their organisational information requirements (OIR), reflecting their strategic objectives, to inform the requirements for particular assets and projects. Thinking about outcomes right from the start, therefore, is critical.

To help organisations do this better, CDBB commissioned PwC to develop a BIM benefits measurement methodology (BMM), which, as well as providing a framework for measuring benefits, also helps organisations define the outcomes they are looking for at key milestones throughout the project and through its operational life.

Defining these benefits and putting timescales to them is essential if organisations are to understand and measure the value of projects. For example, 3D modelling could help with the design of a more energyefficient building but those energy savings will only be realised when the building is in use. The value of using 3D modelling in this instance needs to be understood at the outset. The BIM BMM framework attempts to capture and quantify the value of BIM by identifying direct and immediate cost-savings but also longer-term benefits such as increased productivity, a rise in the value of the asset or ongoing operational savings.

The benefits measurement methodology captures:













Improved asset utilisation



Improvement in asset quality for the end-user



Other, intangible, benefits



Innovation in practice

Using BIM BMM to evaluate the refurbishment of Department of Health headquarters, Victoria Street, London

The refurbishment of the Department of Health headquarters was commissioned in August 2016 and involved ten floors of the existing building, which included a restaurant, conference facilities, meeting rooms, IT rooms, and ministers' offices.

PwC worked with the Department of Health, its main contractor, Willmott Dixon Interiors (WDI), and WDI's supply chain partners, to use the BMM to work out the benefits of BIM Level 2 on completion of the project and those expected to be delivered over the lease period 2016 to 2029.

The overall lifetime saving from 2016 to 2029 achieved by adopting BIM was estimated at more than £650,000 or around 3.0% of the total cost to build without using BIM. PWC estimated that the largest benefits – in both absolute and proportionate terms – will come from the operation phase.

WDI was awarded the Best Overall BIM Project award by the Royal Institute of Chartered Surveyors (RICS) for the 39 Victoria Street refurbishment. This award recognises the delivery of successful BIM projects and initiatives, while promoting best practice and the importance of small and medium-sized enterprises (SMEs) in adopting BIM.

PWC report: BIM Level 2 Benefits Measurement Introductory note: Approach and benefits framework, published March 2018 **pwc**

The overall lifetime saving from 2016 to 2029 achieved by adopting BIM was estimated at more than £650,000 or around 3.0% of the total cost to build without using BIM.



Opportunities for growth

CDBB's international programme



Adam Matthews Head of International, CDBB

The demand for UK BIM expertise is growing around the world, creating significant opportunities for British companies in the global infrastructure market, which is forecast to grow by 70% to US\$15 trillion in 2025³. The international adoption of the UK's open standards and collaborative approach to BIM will further increase the export potential of UK firms. One of CDBB's main tasks is to grow an open and global digital construction market and help to connect the UK construction sector to this opportunity and export more of its products and services.

Our international programme works in partnership with the Department for Business, Energy & Industrial Strategy (BEIS), Department for International Trade (DIT), the Foreign and Commonwealth Office (FCO) and the Infrastructure and Projects Authority (IPA) to help grow the global digital construction market in a way that increases prosperity and improves infrastructure delivery, is open and facilitates trade across national borders.

It develops the capabilities of national governments and public clients in relation to digital construction and emphasises the benefits of a UK approach to information management for the built environment and digital construction in delivering a proven value proposition to the partner country, a strategic programme and a standards-based approach.

A significant part of our activity involves direct engagement with governments and public sector stakeholders in Europe, Latin America, North America, Asia and Africa to build relationships, share learning and secure the collaborative agreements that underpin the implementation of BIM standards across partner countries. We encourage partner countries to visit the UK to observe our BIM experience, access our expertise and hear directly about some of our success stories.

2018 highlights

Promoting export opportunities to UK firms

CDBB chaired a joint event held with the BEIS As a delivery partner in the UK Prosperity and DIT to promote the trade opportunities funded programme to help developing arising from international adoption of the UK's countries build better infrastructure, CDBB BIM standards. The event featured speeches provides expertise on digital construction from Baroness Fairhead, Minister of State for methodologies and builds national Trade and Export Promotion (DIT), and Richard capabilities by delivering training and Harrington MP, Minister for Business and workshops to government officials. With Industry (BEIS), and attracted attendees from BEIS and FCO, we have signed Memoranda of a range of UK construction firms keen to learn Understanding (MoU) with the governments more about the current international BIM of Vietnam, Indonesia and Colombia and landscape. are working with other countries, including Mexico, Brazil and Peru.

Forging links with South America

CDBB welcomed high-level delegations from the Brazilian and Chilean governments as part of a week-long programme showcasing UK digital construction. The delegates heard about the CDBB programme, with talks on a wide range of topics including the Cambridge digital twin, digital transformation strategies and BIM case studies.

Supporting the use of BIM in Chile

CDBB's international director, Adam Matthews, was part of a trade mission of British experts promoting the use of BIM UK protocols in Chile, hosted by the British Embassy and the British-Chilean Chamber of Commerce.

Developing regional hubs

To grow awareness and engagement with the UK BIM methodology internationally, CDBB participated in the inaugural meetings of the Latin American BIM Group and the Asia Regional Group for the public sector held in Hong Kong. CDBB continues to support BIM developments in the LatAm Forum and EU BIM Task Group. These regional groups provide a forum for sharing experience and good practice to build digital construction capabilities.

Working with the UK's Global **Infrastructure Programme**

"When you look at what BIM can do it is obvious why this is happening. It allows governments and companies to de-risk projects, and it improves the design, delivery and operation of assets. The UK is a leader in BIM and our goal in my department is to find ways where we can help UK firms take advantage of the opportunities and succeed overseas."

Baroness Fairhead CBE, Minister of State for Trade and Export Promotion and co-chair of the Infrastructure Exports: UK Board at UK's International Trade Opportunity for Digital Construction, a joint event with the CDBB, BEIS and DIT, October 2018.

CDBB international engagement





Iceland

Sweden

The importance of security



Alexandra Luck Security Project Manager, CDBB

Trust and security are fundamental to a digital built Britain and they are at the heart of the CDBB programme.

Our first challenge is that the processes and systems used for implementing Level 2 BIM were not designed with an understanding of the vulnerabilities that are created and therefore the security implications that arise. To deal with that, information management practitioners are being advised to take "a security-minded" approach. In other words, they need to put in place appropriate and proportionate security measures to deter and/or disrupt hostile, malicious, fraudulent and criminal behaviours or activities. They are also advised to take a "holistic" approach to security, looking at personnel, physical, cyber and cross-cutting issues and solutions, overseen by good governance with clear lines of responsibility and accountability.

However, the successful implementation of a security-minded approach does rely on organisations recognising the issues and working with their supply chains in order to configure standard data, information and modelling systems in ways that protect, and limit access to, the detail of, and information about, sensitive assets.

The security demands of some asset owners on certain projects mean the security-minded approach is not sufficient to mitigate the risks, restricting the ability of those asset owners to exploit the benefits and reduced time and costs that digital engineering facilitates.

Therefore, as we move beyond BIM, it is essential that new developments are underpinned by managed and integrated information that is trusted and secure to an appropriate level. Solutions must be capable of meeting the needs of all sectors and act as "enablers" within the digital engineering process, rather than being perceived, or used, as "blockers" of adoption and/or innovation.

With the current and future acceleration in the use of, and dependence on, information and communication technologies, the risks around data and information collection and acquisition, processing and storage will increase significantly. Platforms, encompassing devices and supporting software will need to be secure by default in order that full functionality is available without compromising security.

While the security workstream continues to develop the mechanisms and information that are needed to increase awareness, understanding, clarity and structure around the security issues and good security practices, it is also developing, and planning for, the security solutions that will be needed to meet future challenges. These solutions will need to be capable of evolving in line with technological advancements, ensuring that any new vulnerabilities are identified and mitigated.

CDBB activities, such as the security-minded event hosted by CDBB and CSIC in November, aim to ensure that security-mindedness is embedded at all levels and stages.

Ten steps to security-mindedness



Understand which of your assets, including data and information,

assets and services and have an up-to-date business continuity

Embed a security culture within your organisation by providing

Have proportionate physical security measures to control access

For additional information about security-mindedness, please visit: http://www.cdbb.cam.ac.uk/AboutDBB/Security

Featured study

Towards a digitally enabled estate: the University of Cambridge

The University of Cambridge estate covers 600,000 square metres and includes 800-yearold buildings alongside state-of-the-art labs, lecture theatres and offices. To manage a portfolio of this complexity, the Estate Management (EM) team needs access to a huge amount of information.

Recognising the benefits of "going digital", EM has committed to creating a fully digitally enabled estate, in line with the government's Transforming Construction Strategy. BIM has a key part to play in this process and the University has invested a significant amount of time and money in establishing it across its capital delivery programme.



University of Cambridge projects delivered using BIM Artist impression of shared facilities hub - used as a case study by Thayla Zomer. Image courtesy of Jestico + Whiles Architects

The digitalisation strategy

Estate Management (EM) has developed a comprehensive information management strategy, including processes and documentation, to support the delivery of BIM in line with the PAS 1192 suite of standards. The goal of a digitally enabled estate is "to provide easy, reliable and timely access to accurate and consistent information across the full asset life cycle from master planning to maintenance and disposal or renewal".

documents in compliance with the PAS standards, including AIR, EIR and BEP templates



Guided by this vision, the EM team began to work towards implementing information management within the capital delivery programme by reviewing the potential uses and benefits of BIM for facilities management. BIM has now been implemented in all of the University's projects, and these projects have already started to demonstrate the value of information management and new digital technologies.

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What are the benefits of BIM for the capital delivery programme and facilities management?

Many project delivery and asset operation tasks are likely to benefit from the incorporation of BIM technologies and BIM Level 2. CDBB researcher and PhD student Thayla Zomer has been conducting a range of case studies to investigate the benefits of BIM implementation for the University of Cambridge's projects. The case studies have demonstrated that various applications of information management have improved the efficiency of the construction process and brought value to the project in diverse ways.

In the early stages of the RIBA1 plan of work, BIM technologies can be used for visual simulation, which project managers described as a benefit when compared to conventional working practices. Using the visual simulation, BIM tools facilitate exploration and assessment of the preliminary design. The BIM model has also been used to perform energy assessments and to look for ways of optimising the proposed design and reducing the structure's life-cycle costs. BIM has also facilitated cost estimation throughout the project, as well as site planning. BIM technologies have also been used to evaluate properties in the area and the impact of buildings on the surrounding buildings.

BIM has also supported phase planning across all the RIBA stages. The process employs a 4D model (that is, a 3D model with the added dimension of time) to plan the sequence of work. This kind of modelling is a powerful tool and provides a clear understanding of project milestones.

In the developed and technical design stages, BIM tools have been deployed for design authoring, design review, coordination and engineering analysis. The use of BIM models

for design review has improved quality and ultimately enhanced user satisfaction with the buildings. Additionally, the use of BIM tools for clash detection has enabled the identification of a range of issues that have been solved in coordination meetings involving all of the stakeholders. The process has enabled the team to make informed decisions and helped to keep the projects on schedule. According to the project managers, the clash-detection workshops have reduced re-work and allowed identification of major clashes between the different pieces of design. The clash detection has yielded cost savings, as the cost of modifying and incorporating the changes is much smaller than it would be on site. The BIM coordination process has also reduced worker hours when compared to the traditional approach.

BIM tools have also supported the design and analysis of the structure, as in the case of Capella, one of the investigated projects. In this project, precast material was used in the construction phase for both the frame and the façade panels to minimise on-site labour and deliveries and to exploit the superior quality of factory construction. The use of BIM supported structural analysis of precast components. When the components came on site, they fitted perfectly.

3D models have also been used for site induction as part of the construction-phase planning, contributing to improving the health and safety of employees on site. In the operational phase, the University will link the facilities management system to a record model, making maintenance and operation of the facility more efficient. BIM will assist shortand long-term planning and decision-making.

Benefits of BIM implementation on University of Cambridge construction projects



well as benefits to site management, health and safety and sustainability

able to identify activities to be performed in the coming weeks

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Benefits of a digitally enabled estate:

the golden thread of information delivering whole-life value



Use of hand-held devices for site inspections with upload to CDE allowed easier inspection of construction works and spotting of defects

Chapter 4

Next Steps



Professor Andy Neely Director of CDBB, and Pro-Vice-Chancellor for Enterprise and **Business Relations**

Year one has given us a strong base to work from and has enabled an application for further InnovateUK funding to continue to develop the research, policy and change needed to help us deliver the safer, healthier and energy-efficient buildings and infrastructure that the UK needs and which are part of the government's Industrial Strategy.

As we partner with MTC and BRE as the Transforming Construction Alliance to deliver the Core Innovation Hub, we will continue to take forward the mission of the digital built Britain programme. Through the CIH, CDBB will continue to deliver the National Infrastructure Commission's recommendation for a framework, pilot projects and a set of principles to guide the development of digital twins for built assets and infrastructure, to ensure that the data is interoperable, supporting better integration of services across the built environment.

Our growing team of researchers will explore how new digital tools, standards and technologies can create new business and export opportunities for the UK infrastructure sector. Technology alone will not deliver change, so we will build an interdisciplinary team to ensure that our social and economic infrastructure is designed, built and operated with the needs and well-being of citizens at its heart. This research will continue to build the evidence base for industry and government to support this fourth industrial revolution and meet the government's ambition to transform construction and infrastructure performance.

This change will need to be coordinated. The Centre's working groups will be instrumental in ensuring we are in partnership with government and industry; building consensus, capacity and alignment towards a digital built Britain. Our international, policy, security and change programmes will continue to support the promotion and adoption of UK standards for information management and the digital transformation in the construction and infrastructure sector at home and abroad, growing sustainable opportunities for UK plc.

I encourage you to keep a close eye on the Centre's website to stay up to date with news, events and funding opportunities.

"As we partner with MTC and BRE as the Transforming Construction Alliance to deliver the Core Innovation Hub, we will continue to take forward the mission of the digital built Britain programme"

and Pro-Vice-Chancellor for Enterprise and Business Relations

The Transforming **Construction** Alliance

CDBB joined with the Manufacturing Technology Centre and BRE to form the Transforming Construction Alliance (TCA) to transform the way that infrastructure in the UK is designed, built and used. The Transforming Construction Alliance brings together experts specialising in digital, manufacturing, building-performance standards and construction technology. It has been awarded £72 million by Innovate UK to deliver the Core Innovation Hub, a key investment to transform productivity in the construction sector within the Transforming Construction programme, funded by the Industrial Strategy Challenge Fund.

Announcing the successful bid at BRE Watford on 30 November 2018, Business & Industry Minister Richard Harrington said:

"We have the opportunity to revolutionise construction in the UK, and the Core Innovation Hub will help us build smarter, greener and more efficient buildings much faster and cheaper than we do now." The Core Innovation Hub will act as the focal point for construction-related innovation, and strengthen links between the research base and businesses. It will support collaboration to develop and commercialise digital and manufacturing technologies for the construction sector to enable the schools, hospitals and infrastructure of the future to be built with strong levels of safety, quality and energy performance.

"The alliance brings together three trusted organisations with strong research, development and engagement programmes to deliver the evidence base and value case for change, alongside those who will benefit most."

> Professor Andy Neely Director of CDBB, and Pro-Vice-Chancellor for Enterprise and Business Relations



"I look forward to working alongside government, industry and the talented teams at MTC, BRE and CDBB to realise the vision of a transformed construction sector."



Robin Webb Deputy Director, Infrastructure and Procurement, Department for Business, Energy & Industrial Strategy (BEIS)

Keith Waller, Programme Director, Transforming Construction Alliance

> The TCA will support collaboration across sectors, offering an opportunity for everyone with an interest in construction to become involved. Follow the progress:

> > www.transformingconstruction.org.uk @TCA_CIH

CDBB Core Innovation Hub research activity

To deliver an ambitious programme to support the TCA's delivery of the Core Innovation Hub, CDBB will work with four leading University of Cambridge academics to coordinate, collaborate and champion a national, multidisciplinary research community.

The Centre and its researchers will be supported by CDBB's Strategic Research Advisory Group, with representatives from academia, industry and government, chaired by Dr Jennifer Schooling.

Foundations

How do we capture and share data across all phases of the asset life cycle?

Led by Professor Michael Barrett

Professor of Information Systems & Innovation Studies and Director of Research at the Cambridge Judge Business School

Michael's research interests range widely across the field of digital innovation and transformation. Topics include: service innovation, digital innovation and co-working spaces, AI and health-care innovation for personalised medicine, FinTech and disruptive innovation in banking.

Asset management and digital twins

How do we use data to better manage assets through life?

Led by Dr Ajith Parlikad

Senior Lecturer in Industrial Systems, Head of the Asset Management Research Group, Institute for Manufacturing, Department of Engineering

Ajith's research focuses on the development of digital twins of complex asset systems, bringing together data from disparate sources to improve infrastructure asset management.

He works extensively with industry and is a member of the UK Digital Twin Working Group. He is also a member of the Cambridge Centre for Smart Infrastructure and Construction's executive committee.

Impact assessment

What are the performance impacts of digital technologies in the built environment?

Led by Dr Gemma Burgess

Principal Research Associate and Acting Director of the Cambridge Centre for Housing and Planning Research, Department of Land Economy

Gemma's research interests include the relationship between housing and ageing, health inequalities, and equality issues more broadly. Her other main strands of research focus on land supply, the planning system, house building, planning obligations and the delivery of affordable housing through the planning system.

Commercial models

What new contracting and business models are needed for the digitally enabled built environment?

Led by Dr Mohamed Zaki

Deputy Director of the Cambridge Service Alliance, Institute for Manufacturing, Department of Engineering

Mohamed's research interest is in the advanced modelling of big data and its application to digital manufacturing and service delivery. He takes an interdisciplinary approach, bringing together a range of data science techniques to address an organisation's problems, particularly those relating to customer experience.



Year One

Acknowledgements

We would like to take this opportunity to thank all who have helped CDBB this year and look forward to continuing to work with this developing and thriving community of innovators and change-makers. Year one has seen CDBB receive a huge amount of support from within the Department for Business, Energy & Industrial Strategy, the University of Cambridge, including the professional services staff who helped with setting up and running the Centre, and partners from across the infrastructure sector. We appreciate the support and guidance we have received from external stakeholders and the wider CDBB community: working together has enabled our rapid progress and the successes contained in this report.

Strategic Advisory Board

Professor Lord Mair (Chair) - Director of Research, Department of Engineering, University of Cambridge

Dr Barry Blackwell - Government Liaison, CDBB, and Head of Digital Transformation – Construction and Built Environment, Department for Business, Energy and Industrial Strategy

Alexandra Bolton - Deputy Director, CDBB

Professor Andy Neely (Chair) - Director of CDBB, and Pro-Vice-Chancellor for Enterprise and Business Relations

Robin Webb - Deputy Director, Infrastructure and Procurement, Department for Business, Energy and Industrial Strategy

A government security advisor

Management Advisory Board

Professor Andy Neely (Chair) - Director of CDBB, and Pro-Vice-Chancellor for Enterprise and Business Relations

Dr Barry Blackwell - Government Liaison, CDBB, and Head of Digital Transformation – Construction and Built Environment, Department for Business, Energy and Industrial Strategy

Alexandra Bolton - Deputy Director, CDBB

Dr Ioannis Brilakis - Laing O'Rourke Reader in Construction Engineering, University of Cambridge

Alexandra Luck - Project Manager – Security Stream, CDBB

Dr Mark Bew - Strategic Advisor, CDBB

Dr Ajith Parlikad - Senior Lecturer in Industrial Systems, IfM, Department of Engineering, University of Cambridge

Dr Jennifer Schooling - Chair of the Research Strategy Steering Group, CDBB, and Director of the Centre for Smart Infrastructure and Construction

CDBB core and project teams

Professor Andy Neely - Director of CDBB, and Pro-Vice-Chancellor for Enterprise and Business Relations

Ian Blackman - Project Management, International

Dr Barry Blackwell - Government Liaison, CDBB, and Head of Digital Transformation – Construction and Built Environment, Department for Business, Energy and Industrial Strategy

Alexandra Bolton - Deputy Director

- Charles Boulton Research Programme Manager
- Amelia Burnett Head of Engagement

Louise Dobson - Centre Administrator

Alanna Gluck - Engagement Manager

Kirsten Lamb - Information Specialist

Richard Lane - International Programme Manager

Adam Matthews - Head of International

Fiona Moore - Level 2 Programme Manager Dr Kate Parsley - Head of Engagement (Maternity Cover)

Nicola Pearson - Head of Change and Technology Transfer (Interim)

Tim Perree - Project Manager

David Philp - Level 2 Communications Manager

Abigail Plet - Centre Administrator

Dr Jennifer Schooling - Chair of the Strategic Research Advisory Group, CDBB, and Director of the Centre for Smart Infrastructure and Construction

Julie Sigles - Research Programme Manager

Andrew Smith - Research Programme Manager

Terry Stocks - Head of Level 2

Nik Thomas - Head of Operations

May Tu - Finance Manager

Angela Walters - Engagement Associate

Researchers

Professor Phil Allmendinger - School of the Humanities and Social Sciences, University of Cambridge

Professor Paul Alexander - Department of Physics, University of Cambridge

James Heaton - Department of Engineering, University of Cambridge

Qiuchen Lu - Department of Engineering, University of Cambridge

Professor Ian Leslie - Computer Laboratory, University of Cambridge

Chara Makri - IfM, Department of Engineering, University of Cambridge

Dr Veronica Martinez - IfM, Department of Engineering, University of Cambridge

Professor Duncan McFarlane - IfM, Department of Engineering, University of Cambridge

Dr Richard Mortier - Computer Laboratory, University of Cambridge

Dr Ajith Parlikad - IfM, Department of Engineering, University of Cambridge

Thayla Zomer - IfM, Department of Engineering, University of Cambridge

Academic Expert Panel

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"Creating a digital built Britain represents a huge opportunity for the UK. It has the potential to transform our construction and infrastructure sector, to make it more efficient, more productive and more environmentally sustainable while improving the quality of life for everyone in the UK."

> Professor Andy Neely Director of CDBB, and Pro-Vice-Chancellor for Enterprise and Business Relations

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engagement@cdbb.cam.ac.uk

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