

BIM Level 2 Benefits Measurement

*Application of PwC's
BIM Level 2 Benefits
Measurement
Methodology to Public
Sector Capital Assets*

Final

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Executive Summary

About this report

On the 10th April 2017, PricewaterhouseCoopers LLP (PwC) were commissioned by Innovate UK to develop a **Benefits Measurement Methodology (BMM)** to measure the potential benefits from applying BIM Level 2 to public sector infrastructure /capital assets¹, and write a subsequent **benefits report** on the application of this BMM to public sector capital assets, detailing the estimated project/asset level benefits arising from the application of BIM Level 2².

This **benefits report** describes the process and results of applying the BMM to estimate the benefits from use of BIM Level 2 on two public sector capital assets. It tests whether the methodology can be applied to estimate economic benefits that may be realised across the asset lifecycle³. It includes application of the BMM to two assets of different types:

1. **The Department of Health (DoH) headquarters, an office building at 39 Victoria Street, London:** where a refurbishment was carried out in 2016-17 using highly mature BIM Level 2 processes, with elements of BIM used in design, and carried through to operation. (BIM Maturity Assessment Tool (BMAT) score = 93% - see Section 2.2).
2. **The Environment Agency's Foss Flood Barrier, York:** where emergency and then permanent upgrade works were undertaken between 2016 and 2018) on the flood barrier and pumping site, using some elements of BIM Level 2 in the design and build and commission phases, to a level of moderate BIM maturity (BMAT score = 62% - see Section 3.2). Once handover is complete, Environment Agency also plans to collect detailed as-built asset data for the Barrier, to be used in the operations phase. We have included examination of the potential benefits from this exercise in our analysis.

The report includes our interpretation of the results and a discussion of the most important lessons we learned through the application of the BMM itself. We also present some key implications for further benefits measurement work, both at the project/asset level and for potential extensions of this work including to programme/organisation level.

About the benefit estimates

The benefit estimates we present in this report are quantified using a 'bottom up' approach through collection of data and supporting assumptions from asset owners and their supply chain partners on the impacts from use of BIM Level 2 as it was (and is expected to be) applied to each asset. Each impact is quantified on an incremental basis, by assessing the difference in the resources required/expended and/or outcomes achieved from using BIM Level 2 on the project/asset; compared to what would have happened under the most plausible

¹ We use public sector 'capital' assets interchangeably with public sector 'infrastructure' assets throughout the report. We include in these definitions all public sector owned social and economic infrastructure including buildings; across all sectors: e.g. health, justice, defence, environment, water, transport (e.g. rail, road).

² Commissioning letter dated 10th April 2017 'BIS Research and Evaluation Framework Agreement – Lot 4 Resources to provide Benefits Methodology on the BIM Programme FWRECR17033INN

³ Asset lifecycle stages are defined in PAS1192-2:2013 which is the specification for information management for the capital/delivery phase of construction projects using building information modelling. See more at <https://www.thenbs.com/knowledge/what-is-the-pas-1192-framework>

alternative scenario (in which BIM Level 2 was not used). We call this the relevant counterfactual case, which we established through discussions with stakeholders for each project/asset.⁴

The value of each benefit is then estimated in monetary terms by applying relevant economic values to the estimated impacts attributed to BIM Level 2. For example, if time is saved in reviewing asset designs using BIM Level 2, the value of the time saved in monetary terms is the cost of labour that would have been required (wage + overheads) for the stakeholders involved to review designs if BIM Level 2 was not used.

The quantified benefit estimates presented in this report do not reflect the **total value of benefits** from application of BIM Level 2 on either project/asset because:

- Our approach to testing the BMM involved focusing our efforts specifically on quantifying a subset of all possible benefits that might exist, based on their likely materiality for the individual project/asset in question and the availability of supporting evidence available.
- In some cases, stakeholders were unable to provide the information needed to support quantitative estimation of benefits identified. The projects/assets we examined were not specially set up in any way to collect the information needed to support benefits calculation, so our approach was heavily reliant upon stakeholders' recollection of detailed project specifics, as well as any data that could be collected in retrospect. There were several cases where, although stakeholders' views supported the existence of a benefit, because of these difficulties, not enough evidence could be obtained to support quantification. Where this was the case, we have included a qualitative explanation of the benefits and the reasons that the evidence needed could not be obtained.

We have developed quantified and monetised estimates of a number of different benefits for each of the two assets. These benefit estimates include *ex-post* estimates of benefits already realised from the application of BIM Level 2, and *ex-ante* estimates of benefits that are expected to be realised in future stages of the asset lifecycle because of the use of BIM Level 2. The benefits are estimated in terms of their value to the UK economy - regardless of whether they may accrue to the public sector asset owner, to the supply chain, to asset users and/or to other parties.⁵ All benefit estimates rely on the expertise of stakeholders consulted in relation to the specific projects examined.

Costs related to implementing BIM Level 2 are not part of the scope of this work; and are not considered in this report.⁶ The benefit estimates in this report are, therefore, not alone sufficient to assess the return on investment in BIM Level 2 for the two projects/assets examined; or more generally for wider public or private sector organisations. The estimates may, however, be used as an input to the 'benefit side' of any relevant cost-benefit analysis. Furthermore, while the benefits estimated in this report may contribute towards the 20% cost reduction target identified in the Government Construction Strategy of 2011⁷, no assessment has been made of the relative importance of the benefits of BIM Level 2 when compared to the benefits generated by the 12 other thematic areas detailed in the Strategy⁸.

⁴ Further explanation of this approach is provided in PwC's *BIM Level 2 Benefits Measurement Introductory note: Approach and benefits framework* document provided to Innovate UK August 2017.

⁵ In line with HM Treasury Green Book guidance, the BMM is based on the principle that "*the purpose of valuing benefits is to consider whether [an option's] benefits are worth its costs, and to allow alternative options to be systematically compared in terms of their net benefits or costs.*" Whether a certain benefit is realised by a government asset owner in practice depends upon market dynamics and commercial arrangements. For more information on this see PwC's *BIM Level 2 Benefits Measurement Introductory note: Approach and benefits framework* document provided to Innovate UK August 2017.

⁶ Investment in BIM Level 2 has associated costs, which for appraisal or evaluation purposes should be calculated on an incremental basis against an appropriate counterfactual in a similar way to benefits. As in the case of benefits, costs may accrue to the government construction client and/or the supply chain, and may also include indirect effects on the wider economy.

⁷ Cabinet Office, 'Government Construction Strategy' (2011), page 3, available at:
<https://www.gov.uk/government/publications/government-construction-strategy>

⁸ *Ibid.*, page 19.

For each project/asset, we have estimated the total value of the expected benefits from use of BIM Level 2 in present value (PV) terms, over the lifetime of the intervention (*that is, the expected period over which the outputs from upfront capital expenditure will be used (before being replaced) and thus may provide benefit*), using a discount rate of 3.5% per annum.⁹ **All costs and benefits in this report are expressed in 2017 real prices, unless otherwise stated.**

DoH: 39 Victoria Street office refurbishment

Working with the DoH and its supply chain partners, we applied the BMM to estimate the benefits realised (and expected to be realised over the lease period) from use of BIM Level 2 through design, build and commission, handover and close out, and through to operation, of its category B commercial office-fit out of 39 Victoria Street.

This resulted in a PV total lifecycle benefit estimate of **£676,907**, which is equivalent to **3.0% savings in total** (*against the without BIM cost*). This is based on an appraisal period of 13 years and 4 months (shown in Table 1), beginning during the design phase in July 2016 and running until the end of the building's existing lease in September 2029.¹⁰ Table 1 shows the breakdown of the benefit estimate by lifecycle stage and benefit category. Cost savings in asset maintenance is the largest benefit item (nearly three fifths of total benefits estimated) driving the highest level of benefits in the operations phase, which represents two fifths of the total cost of the office refurbishment. By lifecycle phase, benefits in operations (73%) were proportionately the largest. Given that operations represents 40% of the overall cost of the refurbishment, the benefits are large in absolute terms. Time savings in build and commission (15%) and time savings in handover (12.5%) were the second and third largest benefits.

Table 1: DoH 39 Victoria Street - Estimated benefits by lifecycle stage and benefit category (PV 2017 real prices)

Lifecycle phase	All	Design	B&C + Handover	Operation
Time period over which benefits are realised	4 July 2016 – 30 Sep 2029 (~13.33 years)	4 July 2016-30 Nov 2016 (~5 months)	24 Oct 2016-20 Sep 2017 (11 months)	20 Sep 2017-30 Sep 2029 (~12 years)
Est. cost of refurbishment (without BIM)*	£22,526,574	£1,163,406	£12,462,844	£8,900,325#
% Est. cost by lifecycle phase (without BIM)	100%	5%	55%	40%
Est. PV benefit from BIM L2	£676,907	£42,366	£141,872	£492,669
PV benefit as % of cost	3.0%	3.6%	1.1%	5.5%
Estimated benefits by category (% of total benefits estimated)				
Time savings in design (6.3%)	£42,366	£42,366		
Time savings in build and commission (15.3%)	£103,872		£103,872	
Time savings in handover (12.5%)	£84,520		£38,000	£46,520

⁹ This is based on Green Book guidance that costs and benefits in an economic appraisal should be calculated over the lifetime of the intervention in question, and in government appraisal costs and benefits are discounted using the social time preference rate of 3.5%. Source: HM Treasury (2018). *The Green Book Central Government Guidance on Appraisal and Evaluation*, pages 7 and 24. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/685903/The_Green_Book.pdf. For further details see Appendix D.

¹⁰ We have used an appraisal period between 4th July 2016 and 30 September 2029 (approximately 13.33 years) to estimate the benefits realised – and that are expected to be realised – from use of BIM Level 2 in relation to the refurbishment of 39 Victoria Street. This is based on assumptions provided by stakeholders that benefits from BIM Level 2 were realised in the design, build and commission, and handover phases; and that the benefits from BIM Level 2 will continue to be realised through to the end of DoH's lease of the building, which concludes September 2029.

Lifecycle phase	All	Design	B&C + Handover	Operation
Cost savings in asset maintenance (57.9%)	£391,592			£391,592
Improved asset utilisation (4.2%)	£28,151			£28,151
Cost savings in refurbishment (3.5%)	£23,463			£23,463
Reduced variance in OPEX (0.4%)	£2,943			£2,943
% benefits in each phase of lifecycle	100%	6%	21%	73%

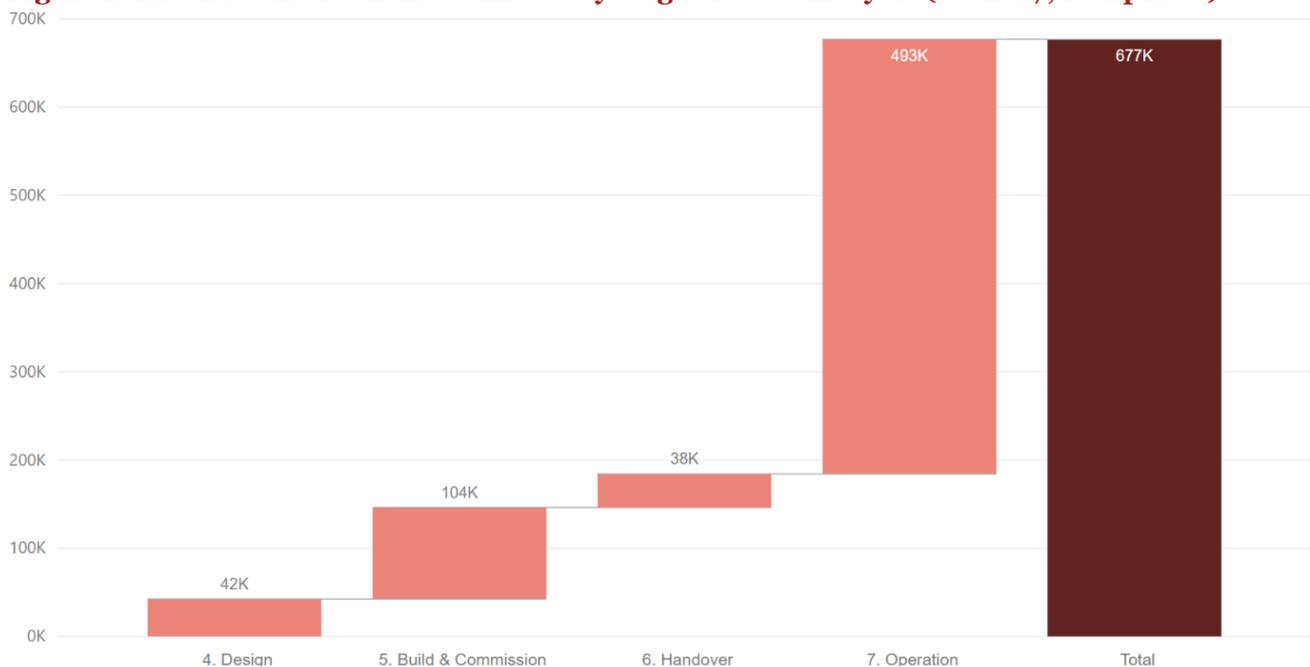
Note: Benefits are expressed in PV terms, real £2017 over a ~13.25 year appraisal period, discounted at 3.5% per annum.

*Costs estimates in 'without BIM' case are calculated by PwC based on actual cost information provided in project documentation by DoH and Faithful + Gould, and adding benefits estimated.

#Note: costs for the operational phase are based on the cost of annual Facilities Management / Maintenance cost provided by DoH. No other ongoing operational costs are included in this estimate to our knowledge.

Figure 1 provides a graphical representation of the size and breakdown of the benefit estimates by phase of the asset lifecycle, benefit category (and, where possible, activity in which the benefit is expected to be realised). It shows clearly that the largest proportion of benefits estimated (73%) is expected to be realised in the operation phase of the asset lifecycle, followed by build and commission and handover (21%), with only 6% of estimated benefits in the design phase.

Figure 1: Breakdown of benefit estimates by stage of asset lifecycle (PV 2017, real prices)



The benefits we include in our quantified estimates were based on initial discussions with DoH and supply chain partners about the refurbishment and the way BIM was used (and is planned to be used) across the building's life. We began with an initial long list of benefits due to the high BIM maturity of the project, and focused on quantifying those benefits for which stakeholders were able to provide the supporting assumptions and data required. There were key benefits that stakeholders thought were likely to exist, that we were unable to measure. Further detail on the reasons for being unable to measure these is provided in Appendix B.2. The benefits we were unable to quantify included cost savings in clash detection; cost savings in rework, from undertaking fewer changes; and savings in materials and the corresponding environmental benefits from this.

Foss Barrier Upgrade

Working with the Environment Agency and its supply chain partners, we applied the BMM to estimate the benefits realised from use of BIM Level 2 in the design, and build and commission phases of the asset lifecycle.

We also applied the BMM to estimate possible future benefits that could be realised in the operational phase in maintenance planning and execution, if Environment Agency carries out its proposed plan to collect detailed as-built asset information for the Barrier and uses the resultant asset information model (AIM) for these purposes.

This resulted in a PV total lifecycle benefit estimate of **£367,693**, which is equivalent to **1.5% savings in total (against the without BIM cost)**. This includes discounting at 3.5% per annum real discount rate across an appraisal period incorporating 25 full years of operations, beginning at completion of the handover phase.¹¹ Table 2 shows the breakdown of this benefit estimate by lifecycle stage and benefit category. Four benefit estimates were quantified in total. Potential future cost savings in asset maintenance are the largest benefit item (over three fifths of total benefits estimated). Time savings in design are the second largest benefit, estimated as 5% of total design cost based on assumptions provided of possible efficiencies due to using BIM in design. Smaller benefit estimates were also quantified for time savings in build and commission, and cost savings in clash detection based on inputs obtained from stakeholders.

Table 2: Environment Agency Foss Barrier Upgrade - Estimated benefits by lifecycle stage and benefit category (PV 2017 real prices)

Lifecycle phase	All	Design	B&C + Handover	Operation
Time period over which benefits are realised	April 2016 – June 2043 (27+ years)	April 2016-May 2018 (26 months) Design and B&C undertaken in parallel		July 2019-June 2043 (~24 years) #
Est. cost of Upgrade (without BIM)*	£23,748,302	£2,632,317	17,683,400	£3,432,584#
Est. cost by lifecycle phase (%) (without BIM)	100%	11%	75%	14%
Est. PV benefit from BIM L2	£367,693	£132,317	£12,257	£223,118
PV benefit as % of cost	1.5%	5.0%	0.1%	6.5%
Estimated benefits by category (% of total benefits estimated)				
Time savings in design (36%)	£132,317	£132,317		
Time savings in build and commission (1.6%)	£5,757		£5,757	
Cost savings in clash detection (1.8%)	£6,500		£6,500	
Cost savings in asset maintenance (60.7%)	£223,118			£223,118
% benefits estimated in each phase of lifecycle	100%	36%	3%	61%

Note: Benefits are expressed in PV terms, real £2017 over an appraisal period including 25 years of operation post upgrade, discounted at 3.5% per annum.

*'Without BIM' Costs estimates are calculated by PwC based on actual cost information provided by Environment Agency in project documentation and by email, and adding benefits estimated.

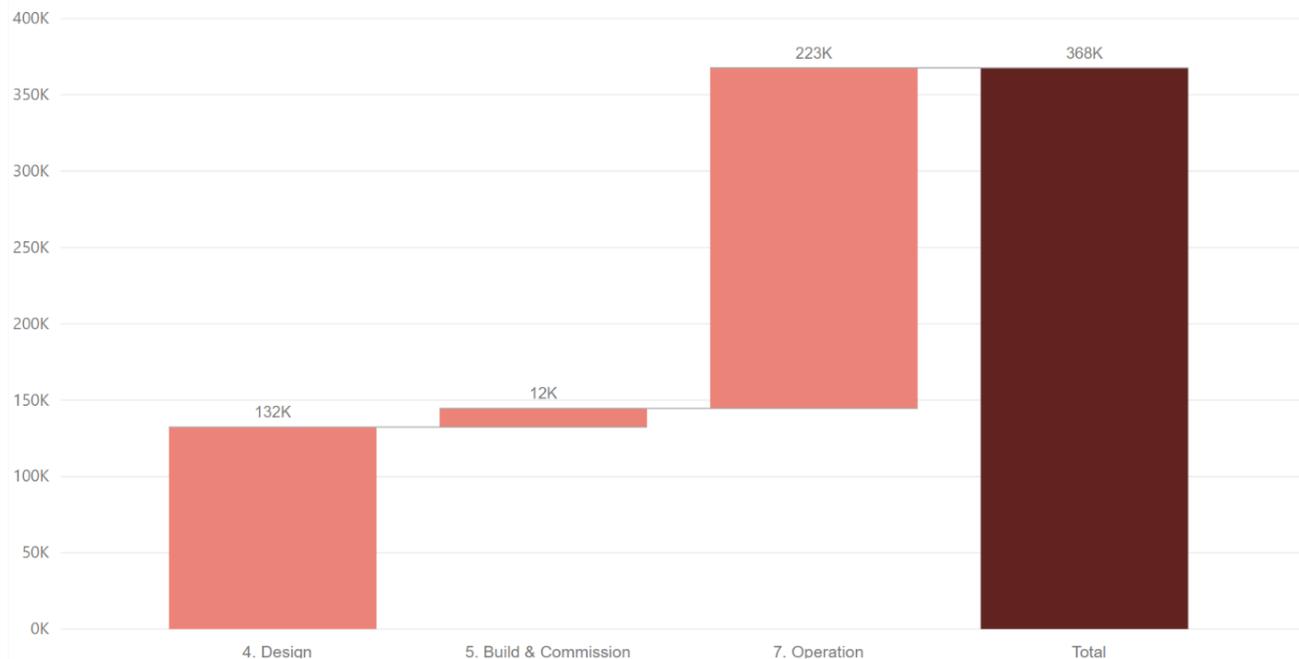
#Benefits in operation are not expected to begin immediately after the handover phase as realisation of benefits in operations is dependent upon Environment Agency collecting and developing an AIM to use in maintenance planning and execution. Stakeholders consulted believe that this process will take a number of months. We have therefore assumed realisation of benefits in operations would begin 10 months after handover of the Upgrade works is complete.

Figure 2 provides a graphical representation of the size and breakdown of the benefit estimates by phase of the asset lifecycle and benefit category. It shows clearly that the largest proportion of benefits estimated (61%) is expected to be realised in the operation phase of the asset lifecycle, followed by design (36%), with only 3% of estimated benefits in the build and commission phase. Operation benefits due to BIM will not occur without

¹¹ We have selected a 25 year appraisal period to assess the possible future benefit from BIM Level 2, beginning from the first full year of operations after the handover period (2018). According to stakeholders consulted, 25 years is the average design life across various mechanical and electrical components (replacement of which comprises a significant proportion of the Foss Barrier Upgrade work). Although the overall design life of the Foss Barrier is 70 years, we assume that the mechanical and electrical components installed as part of the upgrade will be replaced on average in 25 years' time. While it is possible that an asset information model developed of the Barrier could provide benefits beyond this period, it would not be reasonable to quantify benefit estimates beyond this period without also including the likely costs of new Mechanical and Electrical components.

further investment being undertaken by Environment Agency. It is predicated on Environment Agency collecting detailed as-built asset information for the Foss Barrier and using the resulting asset information model for maintenance planning and execution.

Figure 2: Break down of benefit estimates by stage of asset lifecycle (PV 2017, real prices)



The benefits we included in our quantified estimates were based on initial discussions with Environment Agency stakeholders about the Upgrade Works and the way BIM was used (and is planned to be used) across the Barrier's life, and then more detailed consultation with supply chain stakeholders to test our initial hypotheses. We began with a longer list of benefits, although due to the specific project characteristics and its lower BIM maturity (compared to the DoH Office Refurbishment), our list of likely benefits was smaller and more focused than that for the 39 Victoria Street Office Refurbishment outset. There were key benefits that stakeholders indicated had the potential to be material that we were unable to quantify, as described further in Appendix C.2. The benefits we were unable to quantify were further cost savings in clash detection (we were only able to quantify one instance of better clash detection due to BIM Level 2), and cost savings in incident response.

Summary of conclusions and lessons learnt

Our work in applying the BMM to the two public sector assets has led to a number of conclusions and lessons learnt, and thus implications for further measurement work. These are summarised briefly here and described in more detail in Chapter 4 of this report.

Interpretation of quantified benefit estimates

Across our two projects/assets - Foss Barrier Upgrade and the 39 Victoria Street Office Refurbishment - the gross total quantified benefits estimated were 1.5% and 3.0% of whole of life expenditure respectively (on a PV basis using the appraisal periods specified). As outlined below, we believe that this is a lower bound estimate as we were unable to estimate all benefits. These are gross estimates since our analyses have not considered the costs of implementing BIM Level 2.

Across the design, build and commission, and handover phases, our quantified estimates were 0.7% and 1.4% of capital expenditure respectively. If this level of saving could be achieved across the National Infrastructure

Commission's projected public sector funded infrastructure spend of £31.7 billion in 2018/19, this would imply savings to UK taxpayers of £226 - £429 million (in £2017 prices).¹²

We estimate that the largest benefits – in both absolute and proportionate terms – will arise during the operation phase of both assets: they are estimated at 73% of total benefits for the 39 Victoria Street Refurbishment and 61% for the Foss Barrier Upgrade. In both cases the largest source of benefit is in maintenance planning and execution. One reason for this is that the benefits accrue over the expected lifetime of each of the interventions.

Although it is not possible to draw general conclusions based on only two projects, BIM maturity is likely to be one of several factors that influences the scale of benefits that can be realised from application of BIM Level 2 at the project/asset level. The 39 Victoria Street Refurbishment was the most mature project with a BIM Maturity Assessment Tool (BMAT)¹³ score of 93%, and we estimated quantified benefits for 10 'impact pathways' (see Appendix B3 for further details), whereas only eight impact pathways could be quantified for the Foss Barrier (with a BIM maturity of 62%). To determine if there is a possible relationship between BIM maturity and the scale of benefits at the project level that could be generalised across projects/assets, data would need to be analysed statistically for a much larger group of projects.

The difficulties we experienced estimating the quantified benefits from using BIM for clash detection are likely to have reduced the scale of quantified benefits in the 'build and commission' phase for both projects. Although supply chain stakeholders consulted across both projects suggested that use of BIM Level 2 did lead to better clash detection and likely costs savings during on-site construction, they were unable to provide evidence that could be used to estimate the scale of the resultant benefit. Based on analysis of other case studies of the use of BIM Level 2 to detect clashes, the omitted benefits could be significant.

Lessons learned from our application of the BMM

We experienced two key challenges when applying the BMM to estimate the benefits of BIM Level 2 for the two assets:

1. **Obtaining the level of stakeholder engagement required / supporting data to estimate benefits:** our approach relied heavily on engaging stakeholders - both government construction clients/asset owners and their supply chains – to provide inputs to underpin our benefits estimates, and particularly the appropriate counterfactual against which to assess the impact of use of BIM Level 2. While stakeholders were generally supportive, we believe there were several possible reasons for the difficulties we experienced:
 - **Time constraints:** stakeholders had their own jobs to do and timescales to meet.
 - **Hesitancy about their ability to accurately quantify impacts:** all stakeholders we spoke to agreed that our task was difficult due to variations in how BIM was applied on the projects and assessment of its impact across projects. Therefore, in a number of cases, they were able to confirm that a benefit definitely existed, but were not comfortable to provide a judgement on the scale of that benefit.
 - **Reluctance from the supply chain to report benefits:** the contract form applied to design and construction of some public sector infrastructure projects (e.g. sharing cost savings from

¹²Infrastructure and Projects Authority (6 December 2017). Analysis of the National Infrastructure and Construction Pipeline, pg.12-14. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/665332/Analysis_of_National_Infrastructure_and_Construction_Pipeline_2017.pdf

¹³ BIM Maturity Assessment Tool (BMAT) was developed by cross government BIM Level 2 Working Group as a standard tool to measure BIM maturity for public projects. This tool was provided to PwC by BIM Level 2 Working Group to make an assessment of BIM Level 2 maturity for Foss Barrier and 39 Victoria Street projects. Completed BMATs are contained in the Appendix A of this report.

efficiency gains between parties) may have created adverse incentives for the supply chain to share evidence of benefits obtained from their use of BIM.

- **Nature of data requested:** In some instances, commercially sensitive data was not fully available for detailed analysis and only high level estimates were provided.

2. **Deriving an appropriate and likely counterfactual from stakeholder input, for use in quantification:** in some cases stakeholders were unable to provide quantitative estimates of what would have happened if BIM Level 2 had not been used on the project/asset because it was a hypothetical situation, where nobody could know exactly what would have happened in the absence of BIM. As a result, they did not provide sufficient information to allow estimation or they indicated that it was too difficult to know the answer for certain and did not want to guess incorrectly.

Implications for further benefits measurement work

Based on the conclusions and lessons learned from our work, we have identified four key implications for further BIM benefits measurement work at the asset / project level:

1. **Setting up measurement processes at the outset could support more and easier quantification of project benefits.** This would encourage greater focus on both the importance of realising savings from the use of BIM and help to increase understanding of how and what data and evidence needs to be collected to support benefits measurement. Furthermore, this approach could be applied to target the generation and measurement of specific benefits. Integrating concepts from the BMM (e.g. instructions on how to consider impacts against an appropriate counterfactual) into already existing efficiency reporting processes, practices, and documentation used by public sector construction clients and asset owners would be a useful first step. A potential further extension could be to incorporate guidance and requirements for measuring the benefits of BIM into project initiation and stage gate processes, such as the Office of Government Commerce (OGC) Gateway¹⁴ process, or into a new PAS standard.
2. **Sufficient stakeholder engagement and buy-in is essential for success.** This is as important for projects that want to do more to usefully 'self-report' quantified benefit, as it is for measurement undertaken by external parties (such as our work). Construction clients / asset owners need a good relationship with (and sufficient capacity within) their supply chains, as it is most often supply chain stakeholders who have the expertise and knowledge required, and first-hand access to project documentation and other supporting evidence to support appropriate and most accurate quantified estimates.
3. **Relevant technical economics expertise will always be required to assess economic benefits.** Notwithstanding the first and second points above, to correctly apply a Green Book compliant economic estimation methodology (such as the BMM) to any intervention; some level of economics understanding will be required. In quantifying benefit estimates from use of BIM Level 2 at the project/asset level, the most challenging and important aspect is to determine how, and to what extent, BIM affects the resources required and outcomes achieved, and thus the nature and size of the impacts that can be attributed to BIM. The second challenge is then to determine what the value of these impacts are.
4. **Possible extensions of the scope of the BMM application to programmes and organisations.** While this report applied the BMM to two independent projects, estimating only the project-level benefits, the BMM can be applied to estimate potential benefits at a programme or organisational level. Aggregating project level benefits here could potentially create organisational

¹⁴ <https://www.gov.uk/government/publications/ogc-gateway-review-o-strategic-assessment-guidance-and-templates>

efficiencies that exceed a linear extrapolation of project benefits identified in this report. A further extension would be to analyse which organisations in the value chain accrue the benefits identified.

1. Introduction and approach

1.1 Context

The Cambridge Centre for Smart Infrastructure and Construction (CSIC) identified that smart infrastructure is a global opportunity worth between £2 trillion and £4.8 trillion.¹⁵

It is imperative that the UK takes full advantage of this opportunity. As stated in the National Infrastructure Commission (NIC)'s December 2017 report: '**Data for the Public Good**': *Increasing population, economic growth and climate change are putting significant pressure on infrastructure. To address this, the UK's existing infrastructure needs to become smarter: ...Having more information or data about infrastructure assets enables them to be used more productively.*¹⁶ However, it also identifies that as a rapidly evolving field, the case for investing in smart infrastructure is still being demonstrated across sectors. As such there is a '*need to better ... understand the benefits and application of smart infrastructure in a variety of contexts*'.¹⁷

The UK is leading the way in many areas, such as Building Information Modelling (BIM). As early as 2011, the UK Government recognised the importance of digital information for infrastructure. It acknowledged in the 2011 Government Construction Strategy (GCS) that the public sector does not maximise its benefits in public sector construction and asset use. In response the GCS identified BIM as one of 13 thematic areas that could reduce costs by up to 20%¹⁸, and mandated BIM Level 2¹⁹ as a minimum requirement on all centrally-procured public construction projects from April 2016: "*Government will require fully collaborative 3D BIM (with all project and asset information, documentation and data being electronic) as a minimum by 2016.*"²⁰

The GCS 2016-2020 seeks to build on this progress to further improve central government's capability as a client of the construction industry and owner of public infrastructure. It states the aim to "*embed and increase the use of digital technology, including Building Information Modelling (BIM) Level 2*".

There has been positive progress towards BIM Level 2 implementation across government construction clients and infrastructure owners; departments and agencies have undertaken various actions to scale up their use of BIM and digital information in asset construction and operation working with partners in the supply chain. Each organisation is at a different stage in adopting BIM, with some organisations more mature than others. As with any complex large-scale technology driven change, especially one that requires whole-scale change in the ways of working of an entire industry²¹, there have been a number of barriers to uptake and implementation of BIM. These include:

- 1 **Costs to implement** – both on the government and the industry side, costs of investing in new knowledge, training, and supporting systems and processes are inevitable, and it can be difficult to justify these costs when the associated benefits of data-driven digital improvements in infrastructure will not all

¹⁵ Cambridge Centre for Smart Infrastructure and Construction (2016). 'Smart Infrastructure: getting more from strategic assets', available at: <https://www-smartinfrasturcture.eng.cam.ac.uk/files/the-smart-infrastructure-paper>

¹⁶ National Infrastructure Commission (2017). 'Data for the Public Good', page 7-8, available at: <https://www.nic.org.uk/wp-content/uploads/Data-for-the-Public-Good-NIC-Report.pdf>

¹⁷ *Ibid.*, page 23.

¹⁸ Cabinet Office, 'Government Construction Strategy' (2011), page 3 and Annex A.

¹⁹ Our definition of BIM Level 2 is based on PAS 1192-2:2013 and interpretation of its clauses. '*BIM Level 2 is a process of managing information throughout the lifecycle of a built asset, with key features including: the definition of information requirements by the client; the use of a collaborative Common Data Environment; and the use of 3D modelling in design, capturing both geometric and non-graphical data.*'

²⁰ Cabinet Office, 'Government Construction Strategy' (2011), page 14, section 2.32.

²¹ The construction sector is a significant sector for the UK economy, and central government is the industry's biggest customer – as stated in the 2011 GCS, the construction sector "*represents some 7% of GDP or £110bn per annum of expenditure - some 40% of this being in the public sector*".

be realised immediately. (Infrastructure assets typically have a long design life (sometimes over 100 years), so the benefits in improved asset performance and operation will accrue over a much longer time period than the investment required to enable these benefits to be realised).

- 2 **Misaligned incentives when considering investment** – In many cases the responsibility for constructing and maintaining a piece of infrastructure are split between different government entities or different parts of a government entity. Consideration of benefits from investing in BIM are therefore not always taken into account on an infrastructure whole-of-life basis, and upfront investment decisions can be sub-optimal.
- 3 **There is a lack of ‘hard’ evidence of the benefits of BIM** – Because of the two points listed above, some organisations within industry perceive BIM as a net cost. The costs and difficulties involved in changing to more digitally enabled ways of working are easier to understand and quantify than the often more complex and less immediately visible benefits. Benefits can be perceived as less tangible. (For example, in the case of designing and building a new school or road, what is the ‘proof’ that having quicker access to more accurate asset data prevented mistakes from being made and saved time and materials that otherwise would have been wasted?) It is difficult to know for certain what issues could and would have arisen if BIM had not been used, and what the impact of these would have been, in any particular case).
- 4 **There is a lack of consistency in methodology for measuring the benefits of BIM** – there is no specific ‘off the shelf’ methodology that can be consistently applied by government construction clients and asset owners to undertake benefit measurement and evaluation of BIM. Many individual case studies have been developed in the support of the benefits of BIM, in the UK and internationally. These case studies are an important contribution to the evidence base. However, many studies lack explanation of the methodology or basis upon which they estimate benefits, if they provide quantified or monetised estimates at all. It is often unclear against what benchmark or counterfactual scenario these benefits are reported or claimed.

To overcome these barriers, there has been a push from Government to make the public sector a more intelligent construction client, which gains better value from construction, resulting in more productive and higher performing public sector infrastructure. Innovate UK has funded the Digital Built Britain (DBB) Programme with the objectives of delivering a smart digital economy for infrastructure and construction for the future and transforming the UK construction industry’s approach to the way the UK plans, builds, maintains and uses its social and economic infrastructure. DBB’s work comprises multiple areas of research and development, including the BIM Level 2 programme, with the aim of providing strategic leadership to help embed BIM Level 2 as ‘Business As Usual’ within government departments and, in turn, their supply chains.²² The work undertaken by PwC and presented in this report is one contribution to achieving this objective.

1.2 Purpose of PwC’s work

Our work aims to address the last two barriers to uptake and implementation of BIM Level 2, as described above. PwC was commissioned by Innovate UK to develop a **Benefits Measurement Methodology (BMM)** that could be used to measure the potential benefits from applying BIM Level 2 to public sector infrastructure assets, throughout the asset lifecycle²³. The work is intended to support Innovate UK; the DBB Programme; and government construction clients and asset owners to articulate evidenced quantified economic benefits, from the application of BIM Level 2 to public sector capital projects and assets. The methodology is aligned to Green Book, and is intended to provide an approach for estimating benefits that can be applied

²² In November 2017, the UK Government announced the launch of the Centre for Digital Built Britain (CDBB) which will continue the work of DBB Programme, to be based in the Maxwell Centre in West Cambridge and will be formally launched in Spring 2018: <https://www.cdbb.cam.ac.uk/news/2017NovPressRelease>

²³ Asset lifecycle stages are defined in PAS1192-2:2013.

across all types of public sector economic and social infrastructure, and is credible to decision makers involved in assessing public sector spending proposals.

1.3 Progress to date and purpose of this report

The BMM which PwC delivered to Innovate UK in August 2017 comprised:

- A **detailed methodology** providing guidance on how to quantify and monetise eight categories of potential benefits from the application of BIM Level 2 to a capital **project** or **asset**, and how to identify the supporting data required. The BMM was developed to be consistent with the Infrastructure and Projects Authority (IPA) guidance on benefits realisation²⁴; and the HM Treasury Green Book,²⁵ which provides guidance on how to appraise and evaluate the costs and benefits of projects.
- A **benefits framework**, that underpins the BMM and contains a set of 'impact pathways' which describe how the application of BIM Level 2 could lead to benefits for government construction clients and asset owners and/or parts of their supply chains. It was informed by consultation with the BIM Level 2 Working Group, UK government construction clients and asset owners and select members of their supply chains.²⁶

Following development of the benefits framework and the BMM, the current phase of work has involved application of the BMM to two examples of 'real life' public sector assets where BIM Level 2 was (or is being) used. The objectives of this were to:

- Develop a quantified and monetised estimate of economic benefits from the use of BIM Level 2 on the selected assets
- Test the methodology developed to see whether it can be applied consistently to different asset classes, and through the application process identify challenges and lessons learnt to inform next steps for benefits measurement across a wider range of public sector assets.

We have therefore applied the BMM to estimate the benefits from use of BIM Level 2 on two public sector assets:

1. The Department of Health's (DoH's) office refurbishment of 39 Victoria Street, London.
2. The Environment Agency's Foss Barrier Upgrade, York.

This report outlines the approach to, and results from this phase of our work.

1.4 Our approach to applying the BMM

Our approach to the development of the BMM is contained in the 'Introductory Note: Approach and Benefits Framework', provided to Innovate UK in August 2017. This section outlines how we applied the BMM to estimate the benefits from use of BIM Level 2 on the building refurbishment of 39 Victoria Street and the Foss Barrier Upgrade. Figure 1 summarises the overall approach including key steps in the process, the activities involved, and the outcomes and the challenges / lessons learnt at each stage. A more detailed description of the approach applied to each asset and results from stakeholder consultation are provided in Appendix B (39 Victoria Street Refurbishment) and Appendix C (Foss Barrier Upgrade).

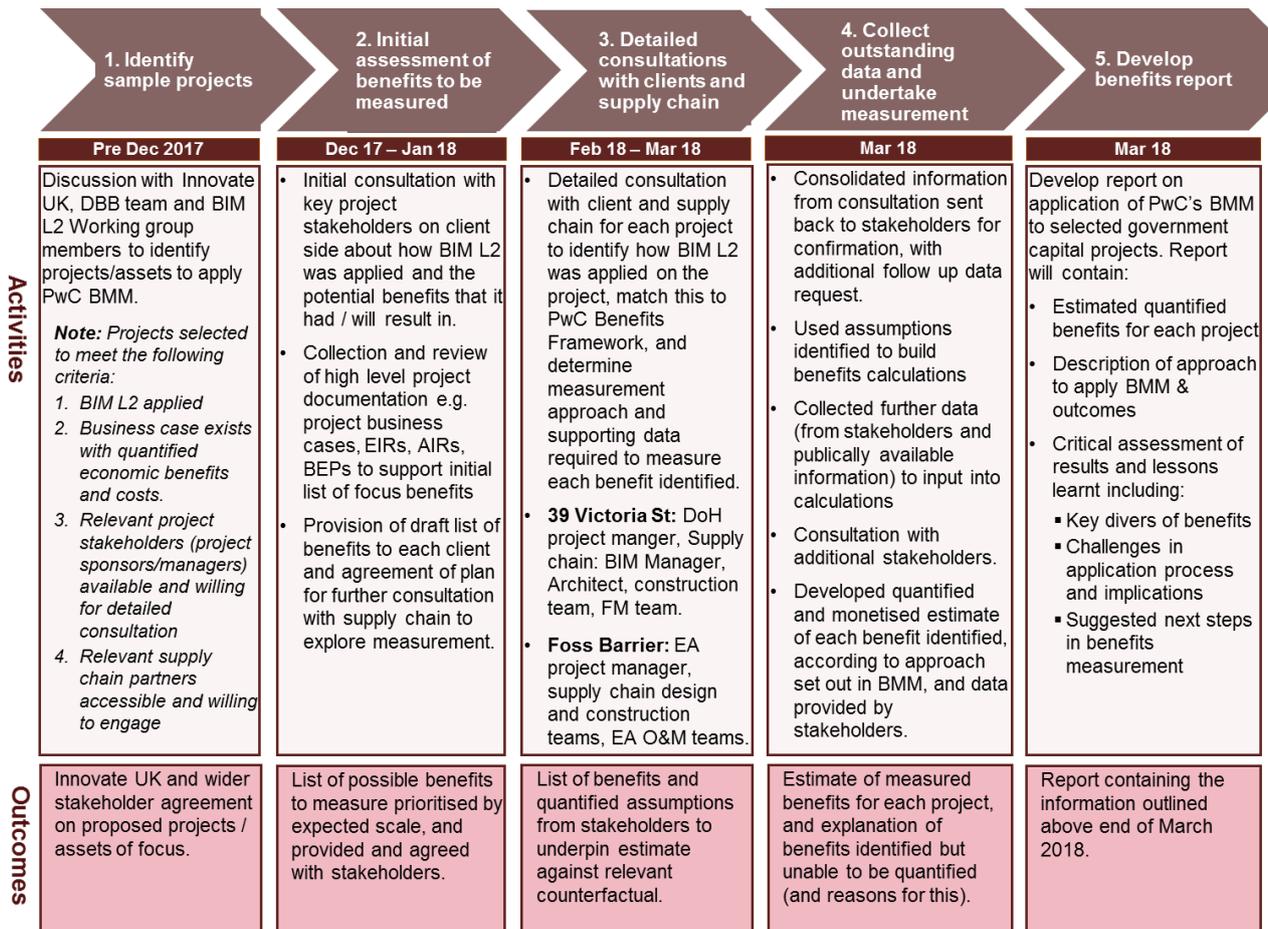
²⁴ Infrastructure and Projects Authority, 'Guidance for Departments and review teams. Assurance of Benefits Realisation in Major Projects. Supplementary Guidance v1, April 2016, available at: <https://www.gov.uk/government/publications/major-projects-authority-assurance-toolkit>

²⁵ Available at:

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/685903/The_Green_Book.pdf

²⁶ Consultees included BIM experts from Highways England, HS2, Cabinet Office, IPA, Thames Tideway, the Ministry of Justice, the Ministry of Defence, the Education and Schools Funding Agency, the Environment Agency, and the Department of Health.

Figure 3: Our approach to applying the BMM



1.5 Remainder of this report

The remainder of this report is structured as follows:

- **Chapter 2: 39 Victoria Street Refurbishment.** This chapter explains the findings from our application of the BMM to the DoH's office refurbishment at 39 Victoria Street. It includes a brief summary of the project, an explanation of how BIM Level 2 was/is expected to be applied at each stage of the asset lifecycle, and a summary of benefit estimates quantified.
- **Chapter 3: Foss Barrier Upgrade.** This chapter replicates Chapter 2 for the Foss Barrier Upgrade.
- **Chapter 4: Conclusions and lessons learned.** This chapter discusses lessons learned from the application process, including key factors influencing the level and type of benefits realised across each project; and challenges experienced in application itself. It also provides our conclusions from the work, including implications for further benefits measurement activity.
- **Appendix A: BMATs.** Here we present completed BIM Maturity Assessment Tools (BMATs), completed by the project teams for both projects/assets. The BMAT assesses the overall level of BIM maturity of a project, based on eight areas of BIM use from project inception to handover into operations.
- **Appendix B: 39 Victoria Street – Estimated benefit measurements.** This contains detailed descriptions of our approach to applying the BMM to the 39 Victoria Street refurbishment, results from the stakeholder consultation process, and the detailed process of how each benefit is estimated: including the relevant benefit pathways from the PwC Benefits Framework; detailed calculations used to estimate each benefit; and supporting assumptions, including those provided by stakeholders.

- **Appendix C: Foss Barrier – Estimated benefit measurements.** This contains the same details as described above for the Foss Barrier Upgrade.
- **Appendix D: Detailed economic assumptions.** This provides additional supporting detailed assumptions used to estimate the economic benefits.

2 Department of Health: 39 Victoria Street Refurbishment

This chapter describes the refurbishment of DoH headquarters at 39 Victoria Street; how BIM Level 2 was (and is being) used across the asset's lifecycle; and how we applied the BMM to identify, prioritise, and measure the potential benefits from the use of BIM. It then summarises the potential benefits identified, and provides quantified and monetised estimates for those benefits we measured.

2.1 Project/Asset Summary

The 39 Victoria Street Refurbishment was a category B commercial office fit-out for the new DoH Headquarters. The refurbishment was commissioned in August 2016 and involved the refurbishment of 10 floors of the existing building including the design and fit-out of a restaurant, conference facilities, meeting rooms, IT rooms, and ministers' offices. The £12.25m project²⁷ (construction cost, assumed £2017 prices) (was delivered as a design and build contract within the Scape 3 framework. This procurement framework provides public body clients with process maps to enable successful delivery of construction projects. The process maps are aligned with RIBA Plan of Work 2013²⁸ and incorporate requirements for BIM Level 2 project delivery such as preparation of Employer's Information Requirements and implementing aspects of Government Soft Landings' (GSL) such as post-occupancy evaluations.²⁹ DoH requirements were to implement BIM Level 2 on the project in accordance with UK Government mandate requirements. This was one of the first fully compliant BIM Level 2 projects undertaken by the main contractor, Willmott Dixon Interiors (WDI), their supply chain, and the client which required the whole project team to work collaboratively to deliver the client's "BIM vision". Design phase including RIBA stages 1-4 was delivered in 10 months from February to November 2016 followed by build and commission phase which finished in September 2017.

Design and construction of the project was undertaken by the main contractor Willmott Dixon Interiors (WDI), with Faithful + Gould (F+G) responsible for project management and delivery of the BIM Level 2 requirements on behalf of Department of Health in collaboration with WDI. Design was undertaken by WDI's in-house team, and construction was led by WDI and supported by their sub-contractors. EMCOR UK were appointed as facilities management contractors towards the end of the project.

WDI were awarded the 'Best Overall BIM Project' award by the Royal Institute of Chartered Surveyors (RICS) for their work on 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. Table 3 summarises key details of the project.

Table 3: 39 Victoria Street office refurbishment summary

Category	Project details
Project Name	Department of Health Headquarters (39 Victoria Street office) refurbishment
Project Type	Category B Office fit-out
Client	Department of Health
Lease length	15 years ending September 2029

²⁷ Information received from Faithful and Gould on 22nd March 2018.

²⁸ Information available on <https://www.ribaplanofwork.com/>

²⁹ Information based on the Process Map contained in <https://www.willmottdixon.co.uk/asset/12303>

Category	Project details
Completion date	Completion of build and commission phase in September 2017
Design cost	£1,083,000 (<i>assumed Nov £2016</i>)
Construction cost	£12,241,000 (<i>assumed Aug £2017</i>)
Annual operations cost [#]	£860,000 (<i>assumed December £2017</i>)
Project Manager	Faithful + Gould
BIM Consultant	Faithful + Gould
Designer	Willmott Dixon Interiors
Lead Contractor	Willmott Dixon Interiors
Facilities Management sub-contractors	EMCOR UK
BMAT maturity score	93%

Sources: Project documentation received from the DoH and Faithful + Gould

*Source: EMCOR UK – average design life of Mechanical and Electrical components stated as 25 years.

[#]Annual cost for FM / Maintenance contract only

2.2 Use of BIM Level 2

The BIM maturity score based on the project team's completion of a BMAT is **93%**, which indicates **high** maturity (full BMAT attached in Appendix A). The BMAT was collaboratively completed by WDI and F+G.

39 Victoria Street Refurbishment followed good practice in the application of BIM, delivering in accordance with BIM Level 2 requirements. The DoH had a clear understanding of the potential benefits from using the asset information in the operational phase, and drove application of BIM from the outset to achieve positive future outcomes. DoH's supply chain responded positively to the challenge of using BIM Level 2, and assisted with implementation of all necessary requirements. Since it was the first BIM project for WDI's supply chain, they were not experienced in creating BIM models or providing Construction Operations Building Information Exchange (COBie) data. To ensure the delivery of the client's BIM requirements, F+G upskilled the supply chain on all aspects of BIM application during the project by providing practical advice on the use of BIM tools and workflows. It was noted that despite steep initial learning curve, the supply chain members found using BIM tools and processes much more effective than conventional methods. For example, one of the quantity surveyors on the project found it much quicker to use the software which imported BIM models to provide a cost estimate for design compared to traditional drawing based estimation.³⁰

WDI supported the creation of the Employer's Information Requirements (EIR) outlining the project information governance and processes in accordance with PAS 1192-2.³¹ They also drafted the pre- and post-contract BIM Execution Plans (BEP) to demonstrate compliance with DoH's requirements. F+G assisted the client with drafting the Asset Information Requirements (AIR) in accordance with PAS 1192-3³² to help deliver benefits in the operations phase. This involved advice from WDI to the client regarding the assets to be included in the Asset Information Model (AIM) and COBie, as the facilities management contractor was appointed later in the construction phase.

Despite the building being refurbished only recently (in 2014 before the DoH leased the building), the existing Operations and Maintenance (O&M) information was of poor quality. WDI undertook a 3D point cloud survey of the existing asset to verify dimensions and provide a base level of information for the Project Information Model (PIM). The survey did not capture the Mechanical and Electrical (M&E) services as WDI did not have full

³⁰ Example provided by WDI during the consultation workshop on the 03 March 2018.

³¹ PAS 1192-2:2013 is the specification for information management for the capital/delivery phase of construction projects using building information modelling.

³² *Ibid.*

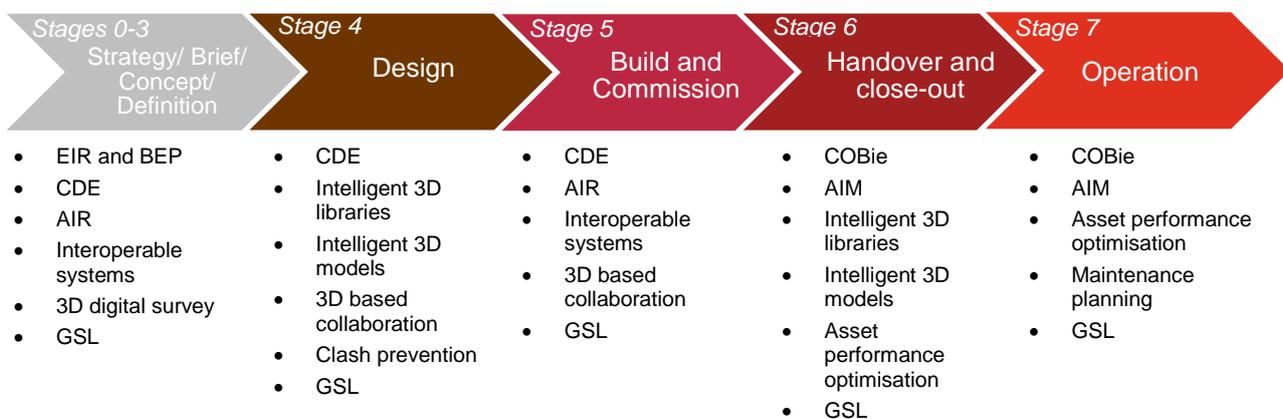
site access to remove suspended ceilings and scan the services (as the lease had not been signed at that time yet by DoH).

WDI applied BIM Level 2 principles in design authoring by using National Building Specification (NBS) BIM Library Objects and specifications in the 3D model. This required initial effort to set up the model but allowed for greater flexibility in future design changes and faster quantity take-offs by the quantity surveyor using CostX software. WDI set up a Common Data Environment (CDE) for the whole project team to proactively collaborate and share the latest design information. WDI as the lead designer federated models from different disciplines and ran fortnightly clash detection reports during the design stage that were discussed during the coordination meetings with the sub-contractors. As a result, based on conversations with WDI during the workshop only four minor clashes occurred on site which had no implications on project cost and programme.

BIM was used for Virtual Reality (VR) visualisations as part of the design reviews with senior DoH stakeholders. This provided a clear view to senior DoH staff of the final appearance and functionality of the refurbishment. This allowed them to provide better feedback to the design team based on their needs for space, so that required adjustments could be made prior to construction. These design reviews formed part of the GSL approach to help ensure that the client and the end users received an asset that performs to their requirements.

Facilities Management contractor EMCOR UK were employed by DoH towards the end of construction period to help plan and deliver the asset maintenance activities. As EMCOR UK were not there in the beginning of the project, there were no set requirements for asset information to be contained in the AIM. To ensure this client requirement was met, WDI included the initial asset information requirements in the EIR document developed for the DoH. When F+G joined the project, they further rationalised and refined these requirements in AIR which included the list of maintainable assets and levels of detail to be provided for each asset. With appointment of EMCOR UK, the asset register was further revised and COBie data mapped to suit the data input into Computer-Aided Facility Management (CAFM) system. Having an AIM which was based on AIR helped reduce the need for additional asset validation survey typically carried out by EMCOR UK to establish the as-built condition. The final asset register formed the basis for defining the scope of the facilities management contract and provided both the client and EMCOR UK transparency in the pricing of maintenance activities. Upon completion of the project the AIM was (and continues to be) maintained by DoH, with data updated as required to support the effective management of the building. This will also help to inform any future changes to the space layout or maintenance operations. Department of Health have undertaken a series of post-occupancy evaluations focused on energy usage and end user satisfaction with the working spaces. Further POE workshops are planned in the future covering other areas for evaluation.³³ Figure 3 shows the key BIM enablers used at each stage of the asset lifecycle that support the realisation of benefits from applying BIM Level 2.

Figure 4: Key BIM Level 2 enablers by stage of asset lifecycle



³³ Based on conversation with Department of Health client representative.

2.3 Summary of estimated benefits

We quantified a total PV benefit estimate of **£676,907** from application BIM Level 2 on the 39 Victoria Street office refurbishment. This is equivalent to **3.0% savings in whole of life (without BIM) asset costs** on a PV value basis, across an appraisal period of approximately 13 and one quarter years beginning during the design phase in 2016 and running until the end of the building's existing lease in September 2029, discounted at 3.5% per annum).³⁴ This includes estimation of benefits across the asset lifecycle as shown in Figure 6. The greatest benefits are estimated to be realised in the Operations phase of the project - 73% of savings, followed by 21% realised in build & commission and handover phases and 6% in design phase.

Figure 5: Value of benefit by benefit category and lifecycle phase - 39 Victoria Street

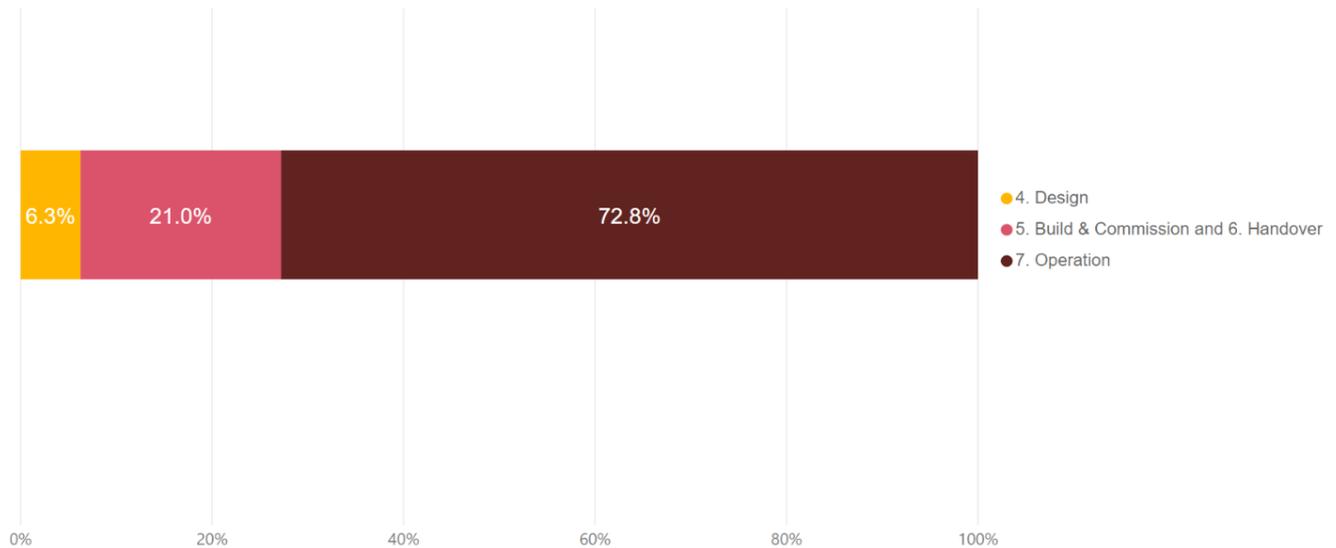


Figure 6 shows further breakdown of benefits by benefits category. The largest single saving from efficiencies in maintenance over the asset lifecycle. As the project is a fit out project, the cost of the design and construction phases is relatively low compared to maintenance spending in operations, so a large saving in this phase is proportional to its larger cost.

³⁴ We have used an appraisal period between 4th July 2016 and 30 September 2029 (approximately 13.25 years) to estimate the benefits realised – and that are expected to be realised – from use of BIM Level 2 in relation to the refurbishment of 39 Victoria Street. This is based on assumptions provided by stakeholders that benefits from BIM Level 2 were realised in the design, build and commission, and handover phases; and that the benefits from BIM Level 2 will continue to be realised through to the end of DoH's lease of the building, which concludes September 2029.

Figure 6: Value of benefits by lifecycle phase – 39 Victoria Street (Present value £2017, based on 25 year appraisal period)

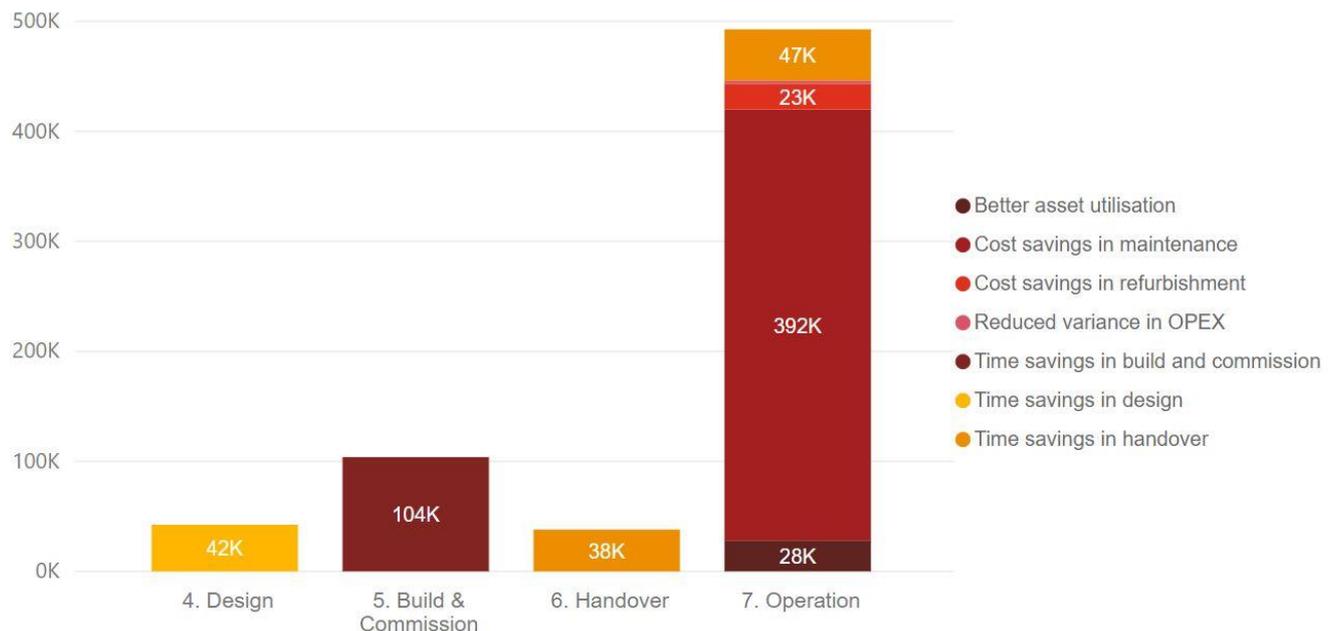


Table 4 shows further information on the benefits identified and quantified at each stage of the lifecycle, including the breakdown of this benefit estimate by lifecycle stage and benefit category. By lifecycle phase, benefits in operations (73 %) were proportionately the largest and operations represents 40% of the overall cost of the refurbishment so in absolute terms these benefits are also large. Time savings in build and commission (15%) and Time savings in handover (12.5%) were the second and third largest benefits.

Table 4: 39 Victoria Street Refurbishment – Summary of project costs and benefits from BIM L2 by lifecycle stage (PV 2017 real prices)

Lifecycle phase	Total	Stages 0-3:	Stage 4: Design	Stage 5 and 6: B&C + Handover	Stage 7: Operation
Time period	8 Feb 2016 - 30 Sep 2029 (~13 years, 8 months)	8 Feb 2016-29 April 2016 (3 months)	4 July 2016-30 Nov 2016 (~5 months)	24 Oct 2016-20 Sep 2017 (11 months)	20 Sep 2017-30 Sep 2029 (~12 years)
Est. cost of refurbishment (with BIM)	£21,849,667	-	£1,121,040	£12,320,972	£8,407,656
Est. cost of refurbishment (without BIM)*	£22,526,575	-	£1,163,406	£12,462,844	£8,900,325#
% Est cost by lifecycle phase (without BIM)	100%	-	5%	55%	40%
Est. PV benefit from BIM L2	£676,907		£42,366	£141,872	£492,669
PV benefit as % of cost	3.0%		3.6%	1.1%	5.5%
Estimated benefits quantified by category (% of total benefits estimated)					
# benefit pathways from PwC BIM L2 Benefits framework quantified	10	0	3	1	6
Time savings in design (6.3%)	£42,366		£42,366		

Lifecycle phase	Total	Stages 0-3:	Stage 4: Design	Stage 5 and 6: B&C + Handover	Stage 7: Operation
Time savings in build and commission (15.3%)	£103,872			£103,872	
Time savings in handover (12.5%)	£84,520			£38,000	£46,520
Cost savings in asset maintenance (57.9%)	£391,592				£391,592
Improved asset utilisation (4.2%)	£28,151				£28,151
Cost savings in refurbishment (3.5%)	£23,463				£23,463
Reduced variance in OPEX (0.4%)	£2,943				£2,943
% benefits in each phase of lifecycle	100%		6%	21%	73%
Benefits identified by stakeholders but not quantified		Time savings (TS) in: <ul style="list-style-type: none"> development of project documentation supply chain procurement, contract award and mobilisation. 	Time savings in design coordination and management	<ul style="list-style-type: none"> TS in construction schedule planning TS in construction quality control Cost savings (CS) from clash detection CS from fewer changes Material savings Environmental benefit from fewer materials used 	<ul style="list-style-type: none"> Improved asset quality Health and safety benefits in maintenance Improved reputation

Note: Benefits are expressed in PV terms, real £2017 over a ~13.25 year appraisal period, discounted at 3.5% per annum.

*Costs estimates in 'without BIM' case are calculated by PwC based on actual cost information provided in project documentation by DoH and Faithful + Gould, and adding benefits estimated.

Those benefit estimates that could be quantified are broken down by 'category' as follows (PV, £2017 over appraisal period). All estimates are quantified on the basis of assumptions provided by stakeholders and operational benefits are estimated as expected to be realised.

- Time savings in design**, which are the savings in the time spent by the architect and other stakeholders in the design stage, estimated at £42,366. These accrue in 4 different activities across the design stage:
 - Product specification
 - Design drawing updates
 - Use of object libraries
 - Cost estimation
- Time savings in build and commission** estimated at £103,872. These accrue to due to less time spent by stakeholders in design reviews in the build and commission phase.
- Time savings in handover** estimated at £84,520. These accrue in 2 different activities at the handover stage and in operations:
 - Savings in carrying out asset validation surveys across asset life.
 - Time savings in import of asset information into CAFM systems (assumed to occur every 5 years over the operation period with a 'handover' of asset information to a new FM contractor.
- Cost savings in maintenance** estimated at £391,592. These comprise:
 - Savings in reactive maintenance.
 - Savings in regular maintenance operations due to better clash detection at the design stage.
 - Additional cost savings in annualised total expenditure (TOTEX = CAPEX + OPEX) due to an increase in the average useful life of asset components from use of BIM to optimise maintenance over the whole life of the asset.

5. **Cost saving due to improved asset utilisation** estimated at £28,151. These are assumed to occur due to reduced probability of asset shutdown due to more accurate understanding of asset condition and avoiding unpredictable component failure due to timely maintenance.
6. **Cost savings in refurbishment** estimated as £23,463. These are assumed to occur when undertaking minor refurbishments (assumed on average twice a year) due to the reduced need to recreate the existing design documentation by using the up-to-date Asset Information Model in refurbishment design.
7. **Savings due to reduced variance in operating expenditures** estimated at £2,943. These are assumed to occur as a result of the FM contractor holding less contingency because of more accurate maintenance costing using BIM.

For further details on each of the benefit estimates please see Appendix B.

3 Environment Agency: Foss Barrier Upgrade

This chapter describes the Foss Barrier Upgrade; how BIM Level 2 was (and is planned to be) used across the asset's lifecycle; and how we applied the BMM to identify, prioritise, and measure the potential benefits from use of BIM. It then summarises the potential benefits identified, and provides quantified and monetised estimates for those benefits we measured.

3.1 Project/Asset Summary

The Foss Barrier and Pumping Station is located at the confluence of the River Foss and the River Ouse. It was originally constructed in 1987 to prevent water from the River Ouse flowing upstream in large storm events. It, was overwhelmed in December 2015 by flooding, which damaged the electrical systems controlling the pumping systems. A temporary works interim solution was used to protect the site and nearby residents, involving the construction of a raised platform to house the pumping station's electrical equipment.

The long term solution was an upgrade to the barrier and pumps – the Foss Barrier Upgrade – which is a permanent works upgrade to the barrier site to improve the flood protection of the nearby community. The works maximise the pumping capacity of the existing pumping station with as little modification to the existing structure of the building as possible. Key elements of the works comprise the upgrade to the capacity of the pumping station through the installation of eight new pumps and associated Mechanical, Electrical, Instrumentation, Control and Automation (MEICA) equipment and constructing an extension to the existing building that will lift all critical equipment above the flood zone.

The result of the upgrade is an increased pumping capacity of over 50%, and increased resilience of the barrier to withstand over a '1 in 1000 year event'. This will allow the pumping station to remain fully operational following a design exceedance event. The upgrade to the barrier will reduce flood risk to 1800+ properties.

Due to the emergency nature of the project and need for immediate action, Environment Agency used existing supply chain partners engaged under the WEM framework to deliver design and construction works³⁵. This enabled design and construction to begin immediately without any delay that would have risked further damage to surrounding properties and possible loss of life. JBA Bentley was appointed as the main contractor under ECC Option C target cost contract to provide the best opportunity of achieving completion in the desired timescales³⁶, and CH2M was appointed as the lead designer. Table 5 summarises key details of the project.

Table 5: Foss Barrier Upgrade summary

Category	Project details
Project Name	Foss Barrier Upgrade
Project Type	Emergency Response and Permanent works upgrade
Client	Environment Agency
Design life	70 years of Barrier in total Estimated average of 25 years for mechanical and electrical components of upgrade.
Completion	Expected completion of 'build and commission' phase September 2018.

³⁵ The Water and Environment Management (WEM) Framework is a commercial agreement between the Environment Agency, consultants and contractors, with agreed terms for the award of individual contracts.

³⁶ Option C is a target cost contract with an activity schedule where the out-turn financial risks are shared between the client and the contractor in an agreed proportion

Category	Project details
Design cost	£2.5 million (<i>assumed December £2017</i>)
Construction cost	£17.7 million (<i>assumed December £2017</i>)
Annual operations cost	£200 thousand (<i>High level estimate of contract cost in the absence of use of BIM in operations, provided by Environment Agency MEICA team – assumed December £2017</i>)
Lead designer	CH2M
Lead contractor	JBA Bentley
BMAT maturity score	62%

Sources: 'Foss Barrier Recovery Project Short Form Business Case' (14/12/2016) provided by Environment Agency, and consultation with Environment Agency stakeholders and supply chain. Note: Includes PwC price adjustments to £2017

3.2 Use of BIM Level 2

BIM maturity score based on Environment Agency completion of BMAT is 62%, which indicates medium maturity (BMAT attached in Appendix A).

Because of the emergency response nature of the project, Stages 0-3 of the asset lifecycle (Strategy, Brief, Concept, and Definition) were effectively not undertaken, which meant that BIM Level 2 processes could not be applied in these contexts. As indicated by the completed BMAT, elements of BIM Level 2 were applied during stages 4 and 5 of the asset lifecycle (design and build and commission), which were undertaken in parallel.

As of April 2016 (when the UK Government mandate for use of BIM Level 2 became effective), all new Environment Agency contracts for design and construction works include an explicit requirement for supply chain use of BIM Level 2 to PAS 1192-2. BIM Level 2 is a requirement under the WEM framework contract, which was used for this project, but as the upgrade works were contracted prior to April 2016, BIM Level 2 was not officially required. However, it was thought at commencement that, given the complexity of the structure, the 3D modelling route would aid the design process and enable client buy-in to the design. Voluntary efforts were therefore made to implement several attributes of BIM Level 2 on the Upgrade by Environment Agency and their supply chain partners.

WEM framework Employer's Information Requirements (EIR) and BIM Execution Plan (BEP) were applied during the design phase of the project. Delivery of Asset Information Requirements (AIR) were outside of the scope.

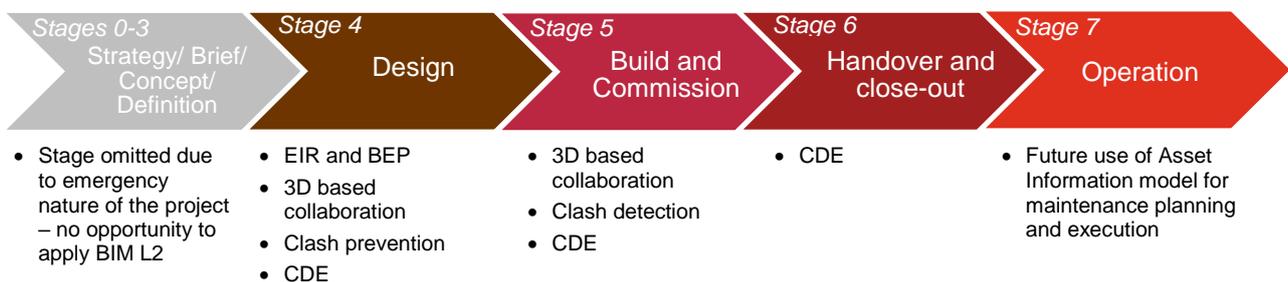
3D laser scan survey was delivered by JBA Bentley which informed the as-built condition of the existing building and served as a basis for the Project Information Model in combination with 2D CAD models. CH2M led the creation of a federated 3D model which was used for weekly clash detection reports, design reviews, construction activity planning and design coordination. CH2M used their Common Data Environment (CDE) as base environment for coordination of design information between the sub-contractors and sub-consultants on the project. Design information was then uploaded to the Environment Agency's CDE in the format and naming convention as specified in EIR.

This year, Environment Agency is intending to start using the Asset Information Models in asset management. Environment Agency plans to collect the required as-built asset information for Foss Barrier, to develop a complete Asset Information Model and COBie data for the Barrier, once construction work is complete. This would then be imported into Environment Agency's new asset register system(s). Currently the Environment Agency has a small number of IT systems for asset information, some of which require data to be manually uploaded. Investment plans are in place to deliver upgrades to improve functionality including the ability to upload structured COBie asset data directly after validation and achieve a reliable trusted source of asset information that will help Environment Agency's asset managers plan and execute whole life asset decisions.

We consulted with Environment Agency stakeholders including the National Asset Performance Teams and the Foss Barrier MEICA maintenance team to develop benefit estimates for the time savings in maintenance that could be realised from having an as-built AIM of the Barrier as described by Environment Agency. This benefit estimate is included in this report.

Environment Agency also has several other BIM Level 2 initiatives in train including development of enhancements to Asset Information Requirements, unlocking data from documents, and development of object type libraries for standardised components. From April 2018, Environment Agency are mandating 3D models in EIR to prepare supply chain to deliver 3D models with data objects by the end of 2018, and parametric objects by June 2019. This means that further implementation of these initiatives could increase the potential for cost savings in asset operation. These have not been considered as part of the estimates we have undertaken for Foss Barrier.

Figure 4: Key BIM Level 2 enablers on Foss Barrier Upgrade by stage of asset lifecycle



3.3 Summary of estimated benefits

We quantified a total PV benefit estimate of **£367,693** from application BIM Level 2 on the Foss Barrier Upgrade. This is equivalent to **1.5 % savings in whole of life (without BIM) asset costs** on a PV value basis, across an appraisal period incorporating 25 full years of operations, beginning at completion of the handover phase).³⁷ This includes estimation of benefits in four different categories across the asset lifecycle as shown in Figure 6. Potential future cost savings in asset maintenance is the largest benefit item (over three fifths of total benefits estimated). Time savings in design is the second largest estimated benefit, estimated as 5% of total design cost based on assumptions provided of possible efficiencies due to using BIM in design. Smaller benefit estimates were also quantified for time savings in build and commission, and cost savings in clash detection based on inputs obtained from stakeholders.

Figure 7 provides a graphical representation of the size and breakdown of the benefit estimates by phase of the asset lifecycle, and benefit category. It shows clearly that the largest proportion of benefits estimated (61%) are expected to be realised in the operation phase of the asset lifecycle, followed by design (36%), with only 3% of estimated benefits in the build and commission phase. Figure 7 provides a further breakdown of benefit values by lifecycle phase and benefit category.

³⁷ We have selected a 25 year appraisal period to assess the possible future benefit from BIM Level 2, beginning from the first full year of operations after the handover period (2018). According to stakeholders consulted, 25 years is the average design life across various mechanical and electrical components (replacement of which comprises a significant proportion of the Foss Barrier Upgrade work). Although the overall design life of the Foss Barrier is 70 years, we assume that the mechanical and electrical components installed as part of the upgrade will be replaced on average in 25 years' time. While it is possible that an asset information model developed of the Barrier could provide benefits beyond this period, it would not be reasonable to quantify benefit estimates beyond this period without also including the likely costs of new Mechanical and Electrical components.

Figure 7: Benefit distribution by lifecycle phase – Foss Barrier

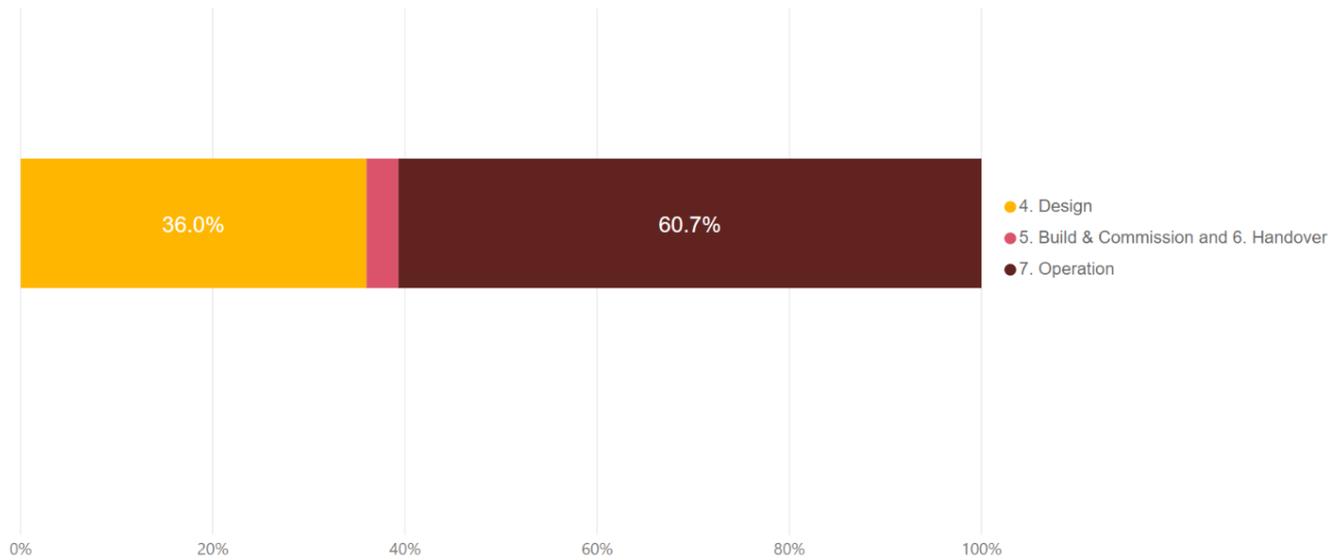


Figure 8: Value of benefit by benefit category and lifecycle phase - Foss Barrier

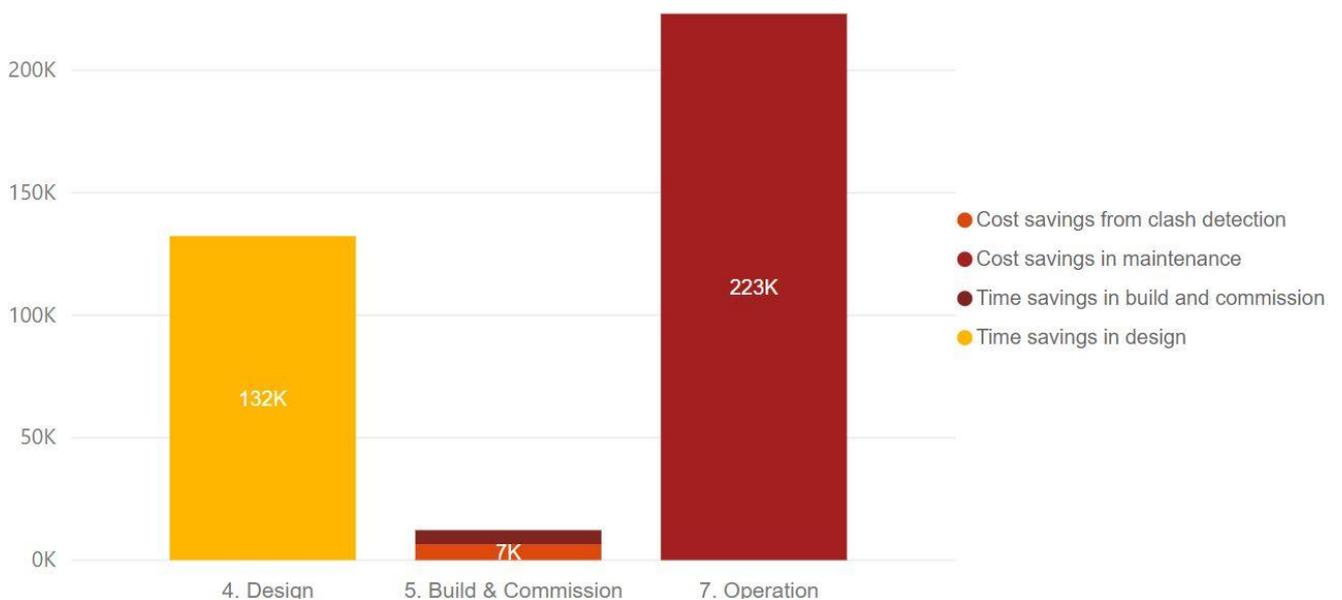


Table 6 shows further information on the benefits identified and quantified at each stage of the lifecycle, including the breakdown of this benefit estimate by lifecycle stage and benefit category.

Table 6: Environment Agency Foss Barrier Upgrade – Summary of project costs and benefits from BIM L2 by lifecycle stage (PV 2017 real prices)

Lifecycle phase	All	Design	B&C + Handover	Operation
Time period	April 2016 – June 2043 (27+ years)	April 2016-May 2018 (26 months) Design and B&C undertaken in parallel		July 2019-June 2043 (~24 years) #
Est. cost of Upgrade (with BIM)	£23,380,609	£2,500,000	£17,671,143	£3,209,466
Est. cost of Upgrade (without BIM)*	£23,748,302	£2,632,317	17,683,400	£3,432,584#
Est. cost by lifecycle phase (%) (without BIM)	100%	11%	75%	14%

Lifecycle phase	All	Design	B&C + Handover	Operation
Est. PV benefit from BIM L2	£367,693	£132,317	£12,257	£223,1189
PV benefit as % of cost	1.5%	5.0%	0.1%	6.5%
Estimated benefits by category (% of total benefits estimated)				
# benefit pathways from PwC BIM L2 Benefits framework quantified	8	3	3	2
Time savings in design (36%)	£132,317	£132,317		
Time savings in build and commission (1.6%)	£5,757		£5,757	
Cost savings in clash detection (1.8%)	£6,500		£6,500	
Cost savings in asset maintenance (60.7%)	£223,118			£223,118
% benefits estimated in each phase of lifecycle	100%	36%	3%	61%
Benefits identified by stakeholders but not quantified		Only partial cost savings in clash detection could be quantified (1 example)		<ul style="list-style-type: none"> • Time savings in incident response • Health and safety benefits in maintenance

Note: Benefits are expressed in PV terms, real £2017 over an appraisal period including 25 years of operation post upgrade, discounted at 3.5% per annum.

*'Without BIM' Costs estimates are calculated by PwC based on actual cost information provided by Environment Agency in project documentation and by email, and adding benefits estimated.

#Benefits in operation are not expected to begin immediately after the handover phase as realisation of benefits in operations is dependent upon Environment Agency collecting and developing an AIM to use in maintenance planning and execution. Stakeholders consulted believe that this process will take a number of months. We have therefore assumed realisation of benefits in operations would begin 10 months after handover of the Upgrade works is complete.

Those benefit estimates that could be quantified are broken down by 'category' as follows (PV, £2017, total over appraisal period). All estimates are quantified on the basis of assumptions provided by stakeholders, including benefits in operation which are estimated as expected future benefits. These benefits will not occur without further investment being undertaken by Environment Agency. Realisation of this benefit is predicated on Environment Agency collecting detailed as-built asset information for the Foss Barrier and using the resulting asset information model for maintenance planning and execution.

1. **Time savings in design:** estimated benefit of £132,317. This is estimated based on stakeholder consultation. The design contractor's view was that at a high level use of BIM could have provided 5% savings in efficiency in the design, mainly because of less time needed to the number of abortive processes in design.
2. **Time savings in build and commission:** estimated value of £5,757. Stakeholders indicated there were time savings due to less time spent on construction schedule planning at the beginning of the build and commission process.
3. **Cost savings from better clash detection:** estimated value of £6,500. The savings accrue from on particular case where a clash between a bus duct and a transformer was detected due to BIM. Stakeholders believed it was not likely that it would have been detected without BIM, and provided evidence of what the cost of re-ordering and installing another bus duct would have been in the case the clash had not been picked up.
4. **Cost saving in maintenance** are estimated as £223,118. These savings have been estimated as possible savings that may occur in the future through use of an as-built information model of the Barrier in planning and executing maintenance. Stakeholders estimated savings could be between 6-7% per annum of both maintenance contract costs and time saved by Environment Agency staff.

For further details on each of the benefit estimates please see Appendix C.

4 Conclusions and lessons learned

This chapter summarises our conclusions and lessons learned from the process of applying the BMM to estimate quantified benefits from use of BIM Level 2 on two public sector capital assets – DoH's 39 Victoria Street office refurbishment and Environment Agency's Foss Barrier Upgrade. It provides our analysis and interpretation of the estimated benefits, describes the challenges we encountered in the process of applying the BMM and how we addressed them, and considers the key implications for further benefits measurement work.

4.1 Interpretation of quantified benefit estimates

Across our two projects/assets, we estimated a range of benefits realisable across various stages of the asset lifecycle. Figure 9 shows the number of benefit pathways (from our BIM Level 2 benefits framework) quantified for each project. The largest number of benefits we quantified estimates for are expected to be (or in the case of 39 Victoria Street Refurbishment may already be starting to be) realised in the operations phase. Stakeholders did not indicate the existence of any benefits realised in asset lifecycle phases before design.

Figure 9: Number of pathways identified by lifecycle phase for each project / asset

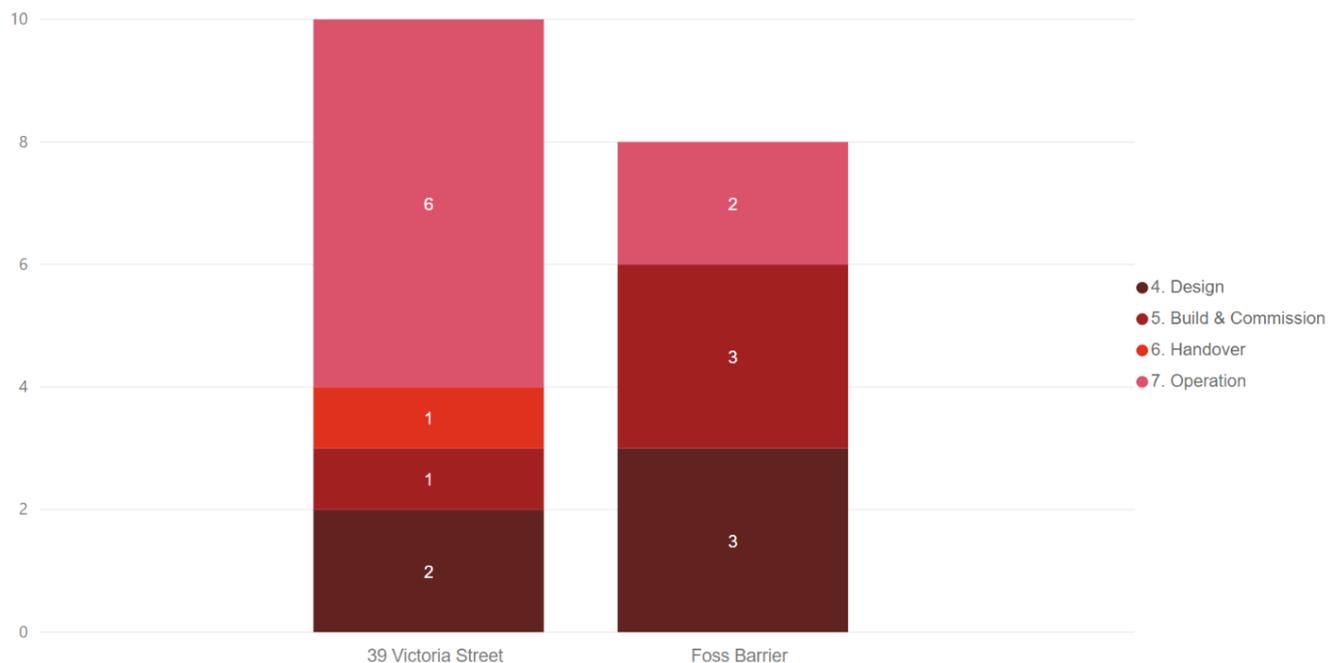
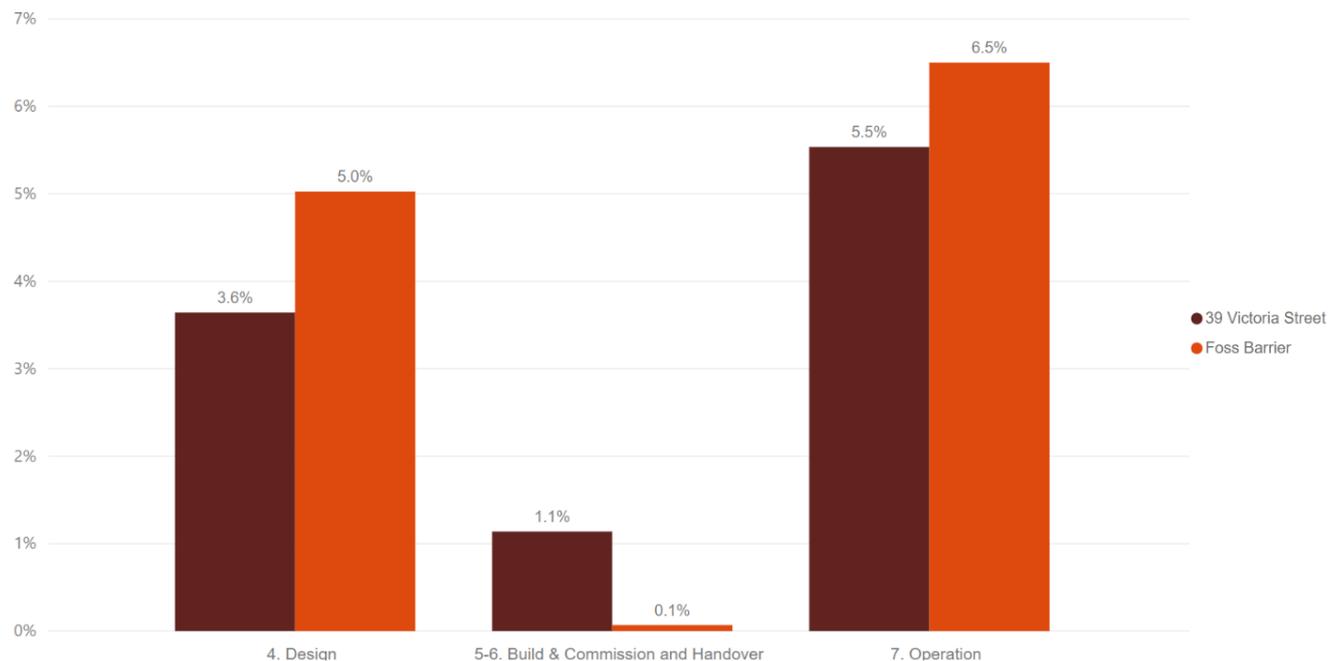


Figure 10 shows our estimates of the benefits for each project/asset as a percentage of the total costs during each phase of the asset lifecycle from design to operation. Across our two projects/assets - Foss Barrier Upgrade and the 39 Victoria Street Office Refurbishment - the total quantified benefits estimated were 1.5% and 3.0% of whole of life expenditure respectively (on a PV basis using the appraisal periods specified).

Across the design, build and commission, and handover phases, our quantified estimates were 0.7% and 1.4% of capital expenditure respectively. If this level of saving could be achieved across the National Infrastructure

Commission's projected public sector funded infrastructure spend of £31.7 billion in 2018/19, this would imply savings to UK taxpayers of £226 - £429 million (in £2017 prices).³⁸

Figure 10: Savings as a percentage of whole lifecycle phase costs for both projects



Key findings across the two projects we examined included the following:

- 1. The value of estimated potential benefits in operations is the largest for both assets.** Benefits in operations make up 73% of total estimated benefits for the 39 Victoria Street Refurbishment, and 61% for the Foss Barrier Upgrade. In both cases the largest source of benefit in operations is in maintenance planning and execution. The quantified estimate of expected maintenance savings for 39 Victoria Street also includes an additional saving from using BIM to optimise maintenance spend across the asset's design life. During consultation, the FM contractor for the building advised that using BIM in this way increases long term visibility of required maintenance across different components of the building upfront. This means that valuable maintenance tasks are less likely to 'value engineered' out of annual maintenance budgets, which is likely to increase the average lifespan across components by 15-20% - thus saving on component replacement costs over the long term.

One reason that benefits in the operations phase are largest is that infrastructure is operated over a number of years. Our PV estimates of total savings in maintenance spend, therefore, include annual savings across approximately 12 years for the 39 Victoria Street office refurbishment and 24 years for the Foss Barrier Upgrade. Sensitivity testing of shorter appraisal periods for each asset shows that the expected value of estimated benefits in the operations phase (in PV terms) will remain proportionately the largest (compared to other phases of the asset lifecycle) for appraisal periods as short as 2 years for 39 Victoria Street, and 12 years for Foss Barrier.

- 2. Higher level of BIM Maturity on 39 Victoria Street project resulted in 10 benefit pathways compared to 8 benefit pathways on Foss Barrier Upgrade with lower BIM maturity.** For the 39 Victoria Street Refurbishment (BIM Maturity self-assessed as 93%) we were able to quantify impacts for 10 benefit pathways (from the benefit framework), as opposed to eight for the Foss Barrier Upgrade (BIM

³⁸Infrastructure and Projects Authority (6 December 2017). Analysis of the National Infrastructure and Construction Pipeline, pg.12-14. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/665332/Analysis_of_National_Infrastructure_and_Construction_Pipeline_2017.pdf

Maturity self-assessed as 62%). The total value of the benefits for 39 Victoria Street across the asset lifecycle up to and including handover was estimated as 1.4% of CAPEX, compared to 0.7% for the Foss Barrier upgrade.³⁹ It is likely that the level of BIM maturity is one of the key factors that influences the number and the value of benefits that can be quantified. More mature clients and their supply chain could be more proponent to apply BIM in variety of project activities throughout the whole asset lifecycle which would increase the opportunities for benefit accrual (e.g. use federated BIM models in site inspections during the construction period rather than just in design process). However, it is likely that there are many other factors which affect the number and value of benefits realised due to BIM including:

- The type of project/asset (e.g. complex, one-off designs may have more to gain from BIM capabilities in design coordination and clash detection).
- The commercial arrangements on projects (collaborative procurement with pain/gain mechanisms could result in more incentives for the supply chain to generate and demonstrate delivery benefits to the client using BIM).
- The ability and/or level of enthusiasm of stakeholders to provide their opinion on the size of any impacts that could be attributed to BIM Level 2, against an appropriate (and somewhat hypothetical) counterfactual (see below for a discussion of our experience from consultations).
- The availability of data for use in quantifying benefits (see below for how this impacted our benefits quantification work).
- The stakeholders' bias (positive/negative) in their assessment of impacts attributed to BIM Level 2.
- The impact of each of the eight elements in the BMAT that are used as components to calculate overall BIM Maturity on benefit realisation (it is not necessarily the case that each element would have the same impact on the value of benefits from BIM that could be achieved on a particular project/asset).

Intuitively, *ceteris paribus*, the higher the BIM Maturity of a particular project/asset, the larger the expected value of the benefits attributed to use of BIM should be. However, to determine any possible causation between BIM Maturity and value of benefits at the project/asset level, data for a much larger number of projects/assets would need to be collected and analysed using statistical methods, controlling for the influence of other factors such as those listed above, to identify whether a statistically or otherwise significant relationship could be established between the two.

- 3. Inability to quantify benefits from using BIM for clash detection is likely to have limited the benefit estimates in the 'build and commission' phase (for both projects).** Our estimate of the benefit for the Foss Barrier Upgrade was 0.1% of CAPEX in 'build and commission' and for 39 Victoria Street it was 1.1% if benefits in handover are included (0.8% if not). Based on stakeholder views it is likely that benefits due to clash detection did exist and could be material on both projects. However, we were unable to identify any benefits from clash detection for 39 Victoria Street, and could only identify one example of an impact relating to a single avoided clash on the Foss Barrier Upgrade. This was despite the supply chain stakeholders who were consulted across both projects stating confidently that they believed that use of BIM Level 2 had led to better clash detection, and likely costs savings from fewer problems during on-site construction. Stakeholders, however, were unable to provide evidence that could be used to assess this benefit for the reasons discussed below. Several case studies published on the use of BIM Level 2 to detect clashes support stakeholders' views that clash detection is likely to be a significant area of benefit when using BIM in infrastructure design. Case studies reviewed include examples of projects where using BIM in clash detection resulted in estimated savings of up to 10% of the total construction contract

³⁹ We cannot include expected benefits from operations in this assessment because estimates for Foss Barrier are predicated upon the expectation that the Environment Agency will invest further in developing an as-built information model for the Barrier to be used in maintenance planning and execution. The BMAT score for the barrier does not take this into assumption into account.

value, against a defined counterfactual in which BIM was not used.⁴⁰ If savings of even 5% of total construction contract value was applied to our projects, an additional £0.7 million in estimated cost savings would be achieved on the 39 Victoria Street Refurbishment, and an additional £1.0 million on the Foss Barrier Upgrade, increasing the percentage of savings in CAPEX during the build and commission phase to 6.4% and 5.3% respectively.

4.2 Lessons learned from the process of applying the BMM

We experienced a number of challenges when applying the BMM to estimate the benefits of BIM Level 2 in two 'real life' public sector assets. These challenges are important findings in themselves and should be used to inform future work undertaken to quantify and evidence the benefits of BIM.

Our challenges can be grouped in two main areas:

1. Obtaining the level of stakeholder engagement required/supporting data to estimate benefits; and
2. Deriving an appropriate and likely counterfactual from stakeholder input, for use in quantification.

4.2.1 Difficulties obtaining the level of stakeholder engagement /supporting data to estimate benefits

Our approach to applying the BMM relied heavily on engagement from stakeholders, both government construction clients/asset owners and their supply chains. Because BMM was applied to both projects retrospectively, our estimates of the economic benefits at the project/asset level are derived from the knowledge and expertise of those people who plan, design, construct, operate, and use those assets. We cannot observe what would have happened if BIM Level 2 was not in use, for a specific project/asset. Hence, establishing the appropriate counterfactual against which to assess the impact of BIM will always require either input from people who have direct experience of working with BIM and understand its impact against the most likely/appropriate alternative method that would have otherwise been used on that project/asset or some sort of statistically based analysis of historic projects which provides the basis for estimating this.

While there are estimates in available literature of time saved or of the proportion of clashes detected due to BIM on certain projects, these estimates are inconsistent. Since the project context and the supporting assumptions are often not reported, it is difficult to understand the basis for the specific analysis undertaken, and therefore, to apply it to different projects. It is also highly likely that the size of these impacts will vary from project to project, and from asset to asset, because of a variety of project/asset specific factors – some of which are more difficult to control than others. From the examples of factors that may influence the existence and size of the benefits from BIM, we found the following ones to be the most frequently occurring: the asset type; the complexity of the asset design; application of elements of BIM; level of skill and experience of design/construction/operation team including BIM skills; size and degree of collaboration between the design/construction/operations teams including level of co-location; willingness of the project teams to use BIM; the types of materials used; and limitations on space at the construction site.

While stakeholders were generally helpful and supportive of our work and every effort was undertaken to get their engagement, we believe there were several possible reasons for the difficulties we experienced in engaging stakeholders:

⁴⁰ See for example Azhar, S., 2011. *Building Information Modelling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry. Leadership and Management in Engineering*, 11(3), pp. 241-252; Kam, C., Senaratna, D., Xiao, Y. & McKinney, B., 2013. *The VDC Scorecard: Evaluation of AEC Projects and Industry Trends*, Stanford: Centre for Integrated Facility Engineering (CIFE), Stanford University.

- **Stakeholder time constraints:** stakeholders (especially from the supply chain or construction project based stakeholders) have their own jobs to do and timescales to meet. Time constraints did appear to be a constraint for project management stakeholders on more than one occasion.
- **Stakeholder hesitancy about their ability to quantify benefits:** There was hesitancy on the part of some stakeholders that it would be too difficult to measure the benefits from BIM. All stakeholders we spoke to (across four possible projects) agreed that our task was difficult due to variations in how BIM was applied on the projects and assessment of its impact across projects (for the reasons described above). Quantifying impacts also depends on making assumptions about what 'would' have happened in an effectively hypothetical counterfactual situation (where BIM was not used on the specific project in question). There was scepticism from some about the ability to gather sufficient evidence to demonstrate the benefits from using BIM, which made engagement challenging.
- **Reluctance from the supply chain to report benefits:** During consultation we clearly explained that the purpose of this work was to test whether that the BMM could be applied in practice, and that the primary objective was to evidence the economic benefits of BIM (the foremost goal not being identification of who those benefits accrue to – i.e. the government client versus the supply chain).⁴¹ However, the contract form applied to design and construction of some public sector infrastructure projects means that any efficiency gains are required to be shared between the supply chain and client. It is possible, therefore, that this may have deterred the supply chain from the sharing evidence of benefits from their use of BIM Level 2, especially if they thought there was a chance it could have a financial cost to them. We do not have any direct evidence that this occurred in practice, but it is possible that this influenced the desire of supply chain stakeholders to engage.
- **Nature of data requested:** In some instances, commercially sensitive data was not fully available for detailed analysis and only high level estimates were provided. We endeavoured to work around this issue as much as possible with stakeholders.
- **Commercial tensions between construction clients and their supply chains reducing cooperation:** For example, when we tried to engage supply chain stakeholders on one potential project, because of what we understood to be contractual issues unrelated to our work, the supply chain was not in a position to support us at that time. For the BMM to be applied successfully it is key that there is buy-in to the process from all key stakeholders.

4.2.2 Difficulties in deriving an appropriate and likely counterfactual from stakeholder input, for use in quantification

In some cases stakeholders were unable to estimate quantitatively what would have happened if BIM Level 2 had not been used on the project/asset. The main reason for this is that the counterfactual where a specific project is concerned, is by nature a hypothetical situation, and it is not possible for anyone to know exactly what would have happened in any given situation on a specific project in the absence of BIM. In some cases, the details provided by stakeholders were not sufficient to allow measurement as they could not commit to providing quantitative assumptions, even at a high level or as an indicative range. In a number of cases stakeholders indicated that it was too difficult to know the answer for certain and, therefore, they did not want to guess incorrectly, or provide verification of suggested assumptions that may turn out not to be accurate. We believe that the impact of this on the quantified benefit estimates is that they are conservative estimates, and would be higher if more information was provided (particularly in the case of the Foss Barrier Upgrade).

An instance of this was clash detection. As explained in Appendix C, Environment Agency and supply chain stakeholders all agreed that use of BIM resulted in benefits due to less rework required because of better clash

⁴¹ This is the method required by HM Treasury Green Book guidance to estimate economic benefits when assessing public sector spending proposals.

detection. However, in retrospect, they were unable to provide an opinion on the scale of these savings. It would potentially be possible to do this by examining clash reports line by line and asking stakeholders to explain each clash, the likelihood it would have been detected without BIM, and the likely impact on the cost of rework for those clashes that were not likely to have been detected if BIM was not used. This would, however, be significantly resource intensive and inevitably be affected by recollection bias, due to which the participants are more/less likely to recall an example based on the outcome of that. In such a case, participants may fail to recall instances of small benefits leading to underestimation. On the other hand, if we believe that the instances remembered are typical of all clash detection benefits, we may overestimate them. For this reason, only one example of savings from better clash detection could be quantified and we did not extrapolate using this.

4.3 Implications for further benefits measurement work

Based on our analysis of the impacts we were able to estimate quantitatively and the lessons we learned through application of the BMM to the two projects, we have identified four key implications for further BIM benefits measurement work.

4.3.1 Setting up measurement processes at the outset could support easier quantification of project benefits

While we have estimated some benefits from applying BIM on both our case study projects, there have been challenges associated with applying our methodology retrospectively, especially after the potential benefits were realised. We think that more benefits could be estimated by putting in place measurement processes at the inception of a project. This would allow more focus to be attributed to savings arising from using BIM in Stages 0-3 of the asset lifecycle for example, where early use of BIM has the potential to enable significant benefits. This could potentially increase the benefits achieved by making benefits measurement easier.

Developing useful processes and practices for measuring benefits from the outset of a project would include identification of which benefits are most useful to measure (e.g. those believed most likely to be material based on project characteristics); defining an appropriate counterfactual against which each benefit will be measured (e.g. if BIM Level 2 was not used for clash detection, what processes and systems would be used instead); and, establishing based on this what questions need to be asked and what data needs to be collected to measure the impact from use of BIM Level 2 (as well as planning how this will be done and who is responsible).

During consultation, Environment Agency project management and supply chain stakeholders agreed that if the Foss Barrier Upgrade project team had prepared from the outset to collect relevant information about clashes, quantifying the benefits of cost savings from clash detection due to use of BIM Level 2 would have been possible. (This would have included including making a judgement in real time about whether a specific clash would have been identified if BIM Level 2 was not used on the project, and if not, recording the likely cost impact that clash could have had if not detected until construction.)

We are aware of instances where government construction clients have collected or are attempting to collect information similar to this, for example in efficiency reporting practices undertaken by Highways England, and in new supplier contract requirements being developed by High Speed 2. Applying the concepts from the BMM to these practices could offers some assistance in collection of the data needed to estimate benefits based on good practice principles, against an appropriate counterfactual, in line with HMT Green Book guidance.

A potential further extension would be to incorporate associated requirements for measuring the benefits of BIM as part of project initiation and stage gate processes, such as the Office of Government Commerce (OGC) Gateway⁴² process, or into a new PAS standard.

⁴² <https://www.gov.uk/government/publications/ogc-gateway-review-o-strategic-assessment-guidance-and-templates>

4.3.2 Sufficient stakeholder engagement and buy-in is essential for successful project-level benefits measurement

Despite best efforts, there were times over the course of our work where we could not obtain a sufficient to level of engagement, and/or time from necessary stakeholders to undertake benefits measurement as originally planned. There were various reasons for that stakeholders may have been in some cases reluctant to fully engage, including: unrelated commercial sensitivities between the key parties; competing demands of critical 'business as usual' activity; and the potential for our benefits measurement work to offer a different view to other efficiency saving work being undertaken. These difficulties did result in delays to our work, and meant we needed to change the projects initially proposed.

By working closely with the BIM Level 2 team, we were able to switch our measurement efforts to focus quickly on the DoH office refurbishment of 39 Victoria Street. Because this project is cited (by the supply chain itself) as a best-practice project for application of BIM Level 2, and has won awards that demonstrate this (see Section 2.1 and 2.2), engagement with the supply chain and the DoH client was much easier and quicker to arrange. While our consultations were undertaken in a manner that attempted to reduce any optimism bias, the status of the project could have led stakeholders to potentially overestimate some of the benefits that could be attributed to BIM.

If future measurement efforts at the project/asset level are undertaken, projects that self-report and promote evidenced benefits of BIM Level 2 are likely to provide easier case studies, due to a higher level of enthusiasm of stakeholders to participate in the engagement process (particularly from the supply chain perspective). This raises the risk, through selection bias, that stakeholders may overestimate benefits achieved, which should be taken into account in assessment and reporting of any findings, and in extrapolating these findings to other projects.

4.3.3 Expertise to facilitate the measurement of benefits

The nature of the workshops and the stakeholder consultation required to apply the BMM using the approach outlined in this report, required a mix of construction (including BIM) and economics expertise. In order for the facilitators to obtain the necessary information, familiarity with the BMM and an understanding of how to establish an appropriate counterfactual were needed. This required both economics and construction industry expertise, including knowledge of processes that are BIM related and non-BIM related. This combination of expertise helped to frame the identification and quantification of benefits, including asking the right questions to prompt stakeholders for the information needed to support measurement.

Extending the application of the BMM, as outlined in Section 4.3.4, would likely be more resource intensive than the work we have undertaken to date to estimate quantified benefits on two standalone assets/projects, because more stakeholders would need to be engaged and consulted at programme/organisation level. It would also still require some combination of the technical skills identified above.

4.3.4 Possible extensions of the scope of the BMM application to programmes and organisations

While we have applied the BMM to two projects, it could also be applied to estimate the benefits that may exist at programme and organisational level. While our analysis did not test the existence of these benefits, through our consultations for this report stakeholders identified what they believed to be programmatic benefits. For example, where there is a repetitive nature to the projects within a programme, using BIM to help standardise the component parts of the projects might enable greater efficiencies in repetitive design activity. This could provide immediate time savings, but also when aggregated across a programme provide organisational efficiencies, for example by enabling design resource to further improve the efficiency of a design, or enable design teams to become smaller and enable further savings due to reduced office space requirements.

This potential for a broad adoption of BIM to effect or enable changes to organisational processes, means that the benefits generated at the programme/organisational level may exceed the direct summation of benefits occurring at individual project level within a programme.

4.3.5 Possible extensions of the scope of the BMM application to identify beneficiaries of savings from adoption of BIM

A further extension to the methodology developed and contained in the BMM could be to undertake analysis of who the identified benefits accrue to in each case. While this report is focussed on a broad economic appraisal of the benefits from using BIM, a study that articulates who in the value chain realises the benefits may help to support further industry adoption of BIM. This would be particularly effective if focussed on areas of the industry where adoption is currently low and may be holding back the wider industry from realising greater benefits. The commercial arrangements in such circumstances are a key factor in influencing this distribution of benefit realisation through the value chain.

*BIM Level 2 Benefits Measurement:
Application of PwC's BIM Level 2 Benefits Measurement Methodology to Public Sector Capital Assets*

2 BIM Delivery

100%

Information about the questions:

Confirm the suppliers have adequately defined their BIM and information delivery and are delivering to meet the Employer requirement.

- a The supplier has delivered BIM processes as described in the BIM Execution Plan (BEP). Yes
- b The BIM Execution Plan (BEP) is comprehensive, providing sufficient information about how the EIR and IDP are to be delivered at all project stages. Yes
- c A comprehensive Master Information Delivery Plan (MIDP) has been provided, that confirms delivery in response to the entire IDP. Yes
- d The supplier has a nominated Information Manager for the project. Yes
- e The information security requirements are being adhered to and aligned to the general project security requirements. Yes
- f Surveys have been carried out in the format and to the extent described in the EIR/IDP. Yes
- g Design management coordination and optimisation is being carried out as described in the BEP. Yes
- h Commissioning has been or is planned to be supplied as described in the BEP. Yes
- i O&M information has been or is planned to be supplied as described in the BEP. Yes
- j Health & Safety information has been or is planned to be supplied as described in the BEP. Yes
- k The supplier has provided information exchanges as required by the EIR/IDP and as detailed in the suppliers BEP/MIDP. Yes
- l The supplier has provided published stage information exchanges complete with COBie data as defined in the EIR. Yes

Yes

This looks back at the completed stage.
This looks forwards towards the next stage.
The stage at which supplier produces a MIDP will differ depending on how the project is procured.

3 Data, Verification and Validation

100%

Information about the questions:

Confirm information, files and data, is being delivered, verified and validated, to enable the Employer to contractually rely on the information at the appropriate stages, for appropriate purposes.

- a Information and Data security policy is detailed in the Post BEP in line with the EIR and it is being applied. Yes
- b Data is being provided in COBie to BS1192-4. Yes
- c Published information: files and data has been verified (complete) & validated (correct) by the supplier prior to receipt into the Employer's Common Data Environment (CDE). Yes
- d Published information: files and data received is being validated (complete) by the employer on receipt into the Employer's CDE. Yes
- e Employer information verification issues are being reported back to the supplier. Yes

Yes

The answer to this question will depend on the stage at which the supplier is appointed.
If no issues then answer is Yes. Please note that data validation is not a task carried out by the Employer.

4 Collaborative working

100%

Information about the questions:

Confirm that information is being used effectively to promote collaborative working within the supplier project team and with appropriate stakeholders.

- a The Employer CDE has been used throughout the appropriate stages of project by the supplier to PAS1192-3. Yes
- b A Supplier CDE has been used throughout the appropriate stages of the project by the supplier to PAS1192-2. Yes
- c Iterative clash detection and mitigation processes are clearly set out and are being adhered to. Yes
- d Risks are being identified and mitigated by using BIM processes, including, but not limited to, stakeholder engagement and clash detection. Yes
- e The resolved coordinated BIM is being comprehensively referenced for site construction information. Yes

Yes

This depends on the Employer providing a CDE so it is currently an Employer score.
This includes operating a CDE on the Employers behalf.

5 Visualisation / Stakeholder Engagement

100%

Information about the questions:

Confirm that information, models & visualisations, are being effectively used to promote broad engagement and understanding.

- a Regular team reviews are taking place, including with the client team, clearly using an interactive federated model/data. Yes
- b Use of federated model/data to present visualisation has taken place with stakeholders and benefits have been identified. Yes
- c The federated model/data is being used as part of GSL processes by the supplier. Yes
- d The federated model/data is being used as part of GSL processes by the employer/FM provider. Yes

Yes
Yes
Yes
Yes

*BIM Level 2 Benefits Measurement:
Application of PwC's BIM Level 2 Benefits Measurement Methodology to Public Sector Capital Assets*

6 Discipline based model authoring

100%

Information about the questions:

Confirm information authorship and provenance is being used, promoted, maintained and tracked throughout the project lifecycle.

- a Federated discipline based models have been provided with a stage appropriate data sets.
- b The current model reflects the current design intent or as-built condition, as appropriate.
- c Buildability reviews have been carried out using the federated/discipline models.
- d All drawings and documents are also managed and accessible via the supplier and employer CDE.
- e Lower tier suppliers play an appropriate part in model authoring / content.

Yes

7 Construction

40%

Information about the questions:

Confirm the best use of BIM and information is being effectively used in the construction phase of a project.

- a Modelling based planning / efficient construction process is has been undertaken.
- b Visual scheduling / sequencing has been carried out.
- c Model use for safety planning in pre-construction and construction.
- d Model use for testing and commissioning.
- e O&M Manual referenced to the model as a minimum & included in the MIDP.

No
No
Yes
Yes
No

8 Model based estimating and change management

100%

Information about the questions:

Confirm that BIM and information is being effectively used to support cost, carbon and programme management.

- a Model use for cost estimating.
- b Model use for quantity take off.
- c Model use change management / value engineering, including proposed design enhancements and what-if scenario cost impacts/assessments
- d Model use detailed estimating, focusing detail on the parts that have a high risk.

Yes
Yes
Yes
Yes

Comments:

No.	Comment	Question No.	Author
1	We used the Viewpoint workflows to ensure that the information is correct prior to be shared to the correct parties.	3a	AC
2			
3			
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9			
10			

Note: Please include comments that are relevant to the Yes/No scoring only.

*BIM Level 2 Benefits Measurement:
Application of PwC's BIM Level 2 Benefits Measurement Methodology to Public Sector Capital Assets*

2 BIM Delivery

42%

Information about the questions:

Confirm the suppliers have adequately defined their BIM and information delivery and are delivering to meet the Employer requirement.

- a The supplier has delivered BIM processes as described in the BIM Execution Plan (BEP).
- b The BIM Execution Plan (BEP) is comprehensive, providing sufficient information about how the EIR and IDP are to be delivered at all project stages.
- c A comprehensive Master Information Delivery Plan (MIDP) has been provided, that confirms delivery in response to the entire IDP.
- d The supplier has a nominated Information Manager for the project.
- e The information security requirements are being adhered to and aligned to the general project security requirements.
- f Surveys have been carried out in the format and to the extent described in the EIR/IDP.
- g Design management coordination and optimisation is being carried out as described in the BEP.

- h Commissioning has been or is planned to be supplied as described in the BEP.
- i O&M information has been or is planned to be supplied as described in the BEP.
- j Health & Safety information has been or is planned to be supplied as described in the BEP.
- k The supplier has provided information exchanges as required by the EIR/IDP and as detailed in the suppliers BEP/MIDP.
- l The supplier has provided published stage information exchanges complete with COBie data as defined in the EIR.

Yes
yes
No
No
Yes
Yes
Yes
No
No
no
Yes
No

This looks back at the completed stage.
This looks forwards towards the next stage.
The stage at which supplier produces a MIDP will differ depending on how the project is procured.

3 Data, Verification and Validation

80%

Information about the questions:

Confirm information, files and data, is being delivered, verified and validated, to enable the Employer to contractually rely on the information at the appropriate stages, for appropriate purposes.

- a Information and Data security policy is detailed in the Post BEP in line with the EIR and it is being applied.
- b Data is being provided in COBie to BS1192-4.
- c Published information: files and data has been verified (complete) & validated (correct) by the supplier prior to receipt into the Employer's Common Data Environment (CDE).
- d Published information: files and data received is being validated (complete) by the employer on receipt into the Employer's CDE.
- e Employer information verification issues are being reported back to the supplier.

Yes
No
Yes
Yes
Yes

The answer to this question will depend on the stage at which the supplier is appointed.
If no issues then answer is Yes. Please note that data validation is not a task carried out by the Employer.

4 Collaborative working

60%

Information about the questions:

Confirm that information is being used effectively to promote collaborative working within the supplier project team and with appropriate stakeholders.

- a The Employer CDE has been used throughout the appropriate stages of project by the supplier to PAS1192-3.
- b A Supplier CDE has been used throughout the appropriate stages of the project by the supplier to PAS1192-2.
- c Iterative clash detection and mitigation processes are clearly set out and are being adhered to.
- d Risks are being identified and mitigated by using BIM processes, including, but not limited to, stakeholder engagement and clash detection.
- e The resolved coordinated BIM is being comprehensively referenced for site construction information.

Yes
No
Yes
No
Yes

This depends on the Employer providing a CDE so it is currently an Employer score.
This includes operating a CDE on the Employers behalf.

5 Visualisation / Stakeholder Engagement

100%

Information about the questions:

Confirm that information, models & visualisations, are being effectively used to promote broad engagement and understanding.

- a Regular team reviews are taking place, including with the client team, clearly using an interactive federated model/data.
- b Use of federated model/data to present visualisation has taken place with stakeholders and benefits have been identified.
- c The federated model/data is being used as part of GSL processes by the supplier.
- d The federated model/data is being used as part of GSL processes by the employer/FM provider.

Yes
Yes
Yes
Yes

*BIM Level 2 Benefits Measurement:
Application of PwC's BIM Level 2 Benefits Measurement Methodology to Public Sector Capital Assets*

6 Discipline based model authoring

Confirm information authorship and provenance is being used, promoted, maintained and tracked throughout the project lifecycle.

80%

Information about the questions:

- a Federated discipline based models have been provided with a stage appropriate data sets.
- b The current model reflects the current design intent or as-built condition, as appropriate.
- c Buildability reviews have been carried out using the federated/discipline models.
- d All drawings and documents are also managed and accessible via the supplier and employer CDE.
- e Lower tier suppliers play an appropriate part in model authoring / content.

Yes
Yes
Yes
Yes
No

7 Construction

Confirm the best use of BIM and information is being effectively used in the construction phase of a project.

40%

Information about the questions:

- a Modelling based planning / efficient construction process is has been undertaken.
- b Visual scheduling / sequencing has been carried out.
- c Model use for safety planning in pre-construction and construction.
- d Model use for testing and commissioning.
- e O&M Manual referenced to the model as a minimum & included in the MIDP.

No
Yes
Yes
No
No

8 Model based estimating and change management

Confirm that BIM and information is being effectively used to support cost, carbon and programme management.

25%

Information about the questions:

- a Model use for cost estimating.
- b Model use for quantity take off.
- c Model use change management / value engineering, including proposed design enhancements and what-if scenario cost impacts/assessments
- d Model use detailed estimating, focusing detail on the parts that have a high risk.

No
No
Yes
No

Comments:

No.	Comment	Question No.	Author
1			
2			
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Note: Please include comments that are relevant to the Yes/No scoring only.

Appendix B: 39 Victoria Street – Detailed activities, findings and benefit estimates

B.1 Our application of the BMM

Table 7 shows the steps (linked to those described in Figure 1) we took to identify, prioritise, and measure potential benefits arising from the use of BIM Level 2 on the 39 Victoria Street refurbishment project. It provides a description of the detailed activities undertaken and the results and outcomes achieved. It also incorporates the 'stage gates' from our agreed scope of work, and a description of status or progress for each.

Table 7: Application of the BMM to 39 Victoria Street Refurbishment.

Step (from Figure 1)	Detailed activities undertaken	Results / outcomes achieved
2. Initial assessment of benefits to be measured	<ol style="list-style-type: none"> 1. Initial consultation with F+G regarding the BIM maturity of the project and suitability for benefits testing. 2. Initial consultation with the DoH client and F+G to understand the project background and approach to BIM. 3. Reviewed the following documents relating to the project, provided by F+G: <ul style="list-style-type: none"> - Employer's Information Requirements (EIR) - Asset Information Requirements (AIR) - BIM Execution Plan (BEP) 4. Developed a list of potential benefits on which to focus the measurement effort. 	<ol style="list-style-type: none"> 1. Key BIM Level 2 project enablers identified using documentation provided. 2. Potential high-level benefits identified using the BMM framework. 3. The list of benefits prioritised for further testing and attempted measurement.
<p>Stage Gate 1: Passed. Following initial consultation and document review, our recommendation was to proceed with attempted measurement of benefits from BIM Level 2 on DoH 39 Victoria Street project.</p>		
3. Detailed consultations with client and supply chain	<ol style="list-style-type: none"> 1. Conducted workshop with WDI and F+G on the benefits of BIM during build and commission phase. 2. Conducted workshop with WDI and F+G on the benefits of BIM during design phase. 3. Conducted workshop with DoH, EMCOR UK and F+G on the benefits of BIM during the handover and close-out and operation phase. 	<ol style="list-style-type: none"> 1. Detailed benefits for measurement identified and confirmed including: <ul style="list-style-type: none"> - The benefit pathway using the BMM. - Definition of a counterfactual case for every benefit to be measured. - Stakeholders involved in generating the benefit. - Initial estimates of the benefit values for those benefits which workshop attendees were capable and comfortable of providing an estimate. 2. Detailed benefits recorded in project benefit assumptions' summary which was circulated back to the workshop attendees to verify the assumptions and estimates provided.
4. Collect outstanding data and undertake measurement	Regular follow-ups with DoH, WDI, F+G and EMCOR UK to verify the data and receive the outstanding benefit information.	Receipt of verified information for benefit calculation.

Step (from Figure 1)	Detailed activities undertaken	Results / outcomes achieved
5. Develop benefits report	<p>Write chapter of report containing details for DoH 39 Victoria Street Refurbishment (Chapter 2) including:</p> <ul style="list-style-type: none"> • Summary of DoH 39 Victoria street project (Section 2.1) • Explanation of how BIM was used on the project (Section 2.2) • Detailed description of how we applied the BMM to identify, prioritise, and measure potential benefits; and what results were achieved (Section 2.3 – this section) • Discussion of all potential benefits identified and which ones proceeded to measurement stage (Section 2.4) • Quantified and monetised estimate of each benefit measured (Section 2.5) <p>Document lessons learnt and critical assessment of results from application of BMM to 39 Victoria Street Refurbishment (see Chapter 4).</p>	Draft benefits report provided to Innovate UK 26 March 2018 including all details relating to application of the BMM to the DoH 39 Victoria Street project.
<p>Stage Gate 2: Passed. As per our agreed approach we critically assessed the results from applying the BMM to determine what lessons can be learned in benefits measurement. This report documents the lessons learned (Chapter 4).</p>		

B.2 Findings from stakeholder consultation

The application of the BMM resulted in the identification and calculation of 11 benefits on the 39 Victoria Street Refurbishment. A number of additional possible benefits were each discussed with various stakeholders as part of the consultation process, however not all of them could be estimated quantitatively.

Table 8 shows in detail each of the potential benefits (derived from the benefits framework) that we tested with stakeholders during consultation, and the evidence collected about each one. It provides the details of the initial hypothesis for the existence of each benefit (based on early consultation and document review), and shows our assessment of whether the benefit is likely to exist on the 39 Victoria Street refurbishment. Assessment is based on stakeholder comments and evidence provided. The table also shows which benefits we were able to measure based on the information provided. Detailed benefit estimates are provided in Appendix B, Section 3.

Table 8: Results of testing potential benefits for measurement with stakeholders

Initial hypothesis of possible benefits that could be measured				Results / findings / evidence from stakeholder consultation for each benefit		
	Benefit	Activity	Hypothesis	Exist?	Meas.?	Stakeholder comments
1	Time savings in stages 0-3	<ul style="list-style-type: none"> • Develop project business case & information requirements. • Supply chain procurement, contract award and mobilisation. 	Definition of the project information requirements using EIR and AIR during the project inception reduces the time taken to carry out the early project stages including the tender process.	BIM not used as per hypothesis	No	This benefit was discussed during the initial meeting with the client who confirmed that he was intending to use the EIR and AIR templates in future DoH projects (e.g. Quarry House) to save the client team time in tendering process. On the 39 Victoria Street project, this benefit would not be applicable as it was the first BIM Level 2 project; no document templates existed and hence new documents were written for this purpose.

Initial hypothesis of possible benefits that could be measured				Results / findings / evidence from stakeholder consultation for each benefit		
	Benefit	Activity	Hypothesis	Exist?	Meas.?	Stakeholder comments
2	Time savings in design	• Design Authoring	Use of 3D modelling and intelligent 3D libraries (across various design activities) reduces the time taken to carry out the design and implement design changes.	Yes	Yes	Stakeholders identified that there would be the following time savings in design authoring: <ul style="list-style-type: none"> • It was quicker to update design documentation (including drawings) using BIM models. • Use of NBS product specification functionality in the BIM model reduced time to specify products. • Use of object libraries to save time in design detailing. This benefit was realised in design phase.
		• Design coordination and management	Use of CDE reduces the time required to find the right data to enable design coordination.	Yes	No	Stakeholders identified that using the CDE improved the speed of coordination but could not define an appropriate counterfactual and an estimate.
		• Design reviews	Federated design models and visualisations derived from them reduce the time to review the design.	Yes	No	Stakeholders identified it was quicker to prepare design walkthroughs using BIM models than using 2D drawings. This benefit was realised in design and build & commission phases
		• Client review and stakeholder consultation	Federated design models and visualisations derived from them reduce the time to review the design.	Yes	No	Stakeholders described the use of VR visualisations that enabled faster design approvals by the client. This impact from this has been assessed under 'cost savings from fewer changes' so it is not quantified here to avoid double counting.
		• Cost estimation	Use of automated material quantity take-off function allows for quicker estimation of quantities and costs.	Yes	Yes	Stakeholders identified that the Quantity Surveyors used CostX software that utilised the information in the BIM models as a basis for estimation and material take-offs. This model also included NBS BIM objects and product specifications allowing for quicker costing compared to traditional CAD based quantity surveying. This benefit was realised in design phase.
3	Time savings in fulfilling RFIs	• Design authoring • Construction information management	Use of BIM Level 2 process increases the understanding of design by all stakeholders, thus reducing the number of project technical requests. The use of a CDE reduces the time taken to obtain the latest information to answer the RFI.	No	No	Stakeholders used CDE for RFIs but did not think that BIM enabled a quicker response to RFIs on this project.
4	Time savings in build and commission	• Design coordination and management	The use of BIM L2 leads to better design information at the time of construction reducing the time taken to carry out construction.	BIM not used as per hypothesis	Yes	Stakeholders identified that the federated 3D model had been used to review the construction activities and resulted in quicker design review sessions rather than a reduction in the duration of the construction phase. This benefit was realised in build & commission phase.

Initial hypothesis of possible benefits that could be measured			Results / findings / evidence from stakeholder consultation for each benefit		
Benefit	Activity	Hypothesis	Exist?	Meas.?	Stakeholder comments
	<ul style="list-style-type: none"> Construction schedule planning 	Use of BIM of modelling allows for more efficient construction sequence planning.	BIM not used as per hypothesis	No	Stakeholders identified that there could have been benefits in using 4D construction sequencing but BIM was not used for this process on this project.
	<ul style="list-style-type: none"> Construction quality control 	Use of handheld devices on site allows for more efficient management of works and improves visibility of construction defects on site.	BIM not used as per hypothesis	No	Stakeholders identified the use of BIM data with the Fieldview application could have saved time to carry out inspections; however it was not used on this project but will be implemented on future DoH projects (e.g. Quarry House).
5	Cost savings from better clash detection <ul style="list-style-type: none"> Design coordination and management Construction quality control 	Clashes are detected virtually using a federated model rather than during site activities, leading to less wastage of time and materials (costs).	Yes	No	<p>Stakeholders identified that clash detection reduced re-work on site and delays:</p> <ul style="list-style-type: none"> Minimum clashes occurred on site due to regular design coordination using federated BIM model. <p>This benefit was not measured due to lack of hypothetical data on material and time savings from the re-work due to clashes provided by supply chain.</p>
6	Cost savings from fewer changes <ul style="list-style-type: none"> Develop project business case & information requirements Client review & stakeholder consultation 	<p>Utilising Soft Landings and engaging the client within the BIM process reduces the number of unforeseen changes and rework required during construction.</p> <p>Utilising 3D and 4D virtual design simulations and engaging the client within the BIM process reduces the number of unforeseen changes and rework required during construction.</p>	Yes	No	<p>Stakeholders' use of BIM models and VR visuals for senior client reviews resulted in no unforeseen changes during construction as some necessary changes were identified during the walkthroughs. The two aspects to this benefit were:</p> <ul style="list-style-type: none"> Reduced cost of unforeseen changes by using design visualisations in VR to walkthrough clients through design before it was constructed. The client provided feedback that he did not like the dark wood panels in an office and requested for these panels to be changed before they were constructed. <p>This benefit was not measured due to lack of hypothetical data on material and time savings from re-work due to this change provided by supply chain.</p>
7	Cost savings in refurbishment <ul style="list-style-type: none"> Refurbishments and upgrades 	AIM provides quicker access to accurate asset information.	Yes	Yes	<p>Stakeholders identified that in the future the design team can use the AIM for design of further upgrades to the asset. This will require significantly less effort during early design and enables spaceproofing works to be carried out quickly.</p> <p>This benefit is expected to be realised in the operation phase.</p>
8	Time savings in handover <ul style="list-style-type: none"> Test assets Handover asset and associated information to client 	Use of COBie and an up to date Asset Information Model allows for faster handover post commissioning.	Yes	Yes	Stakeholders described that importing the COBie and AIM data had the following impacts:

Initial hypothesis of possible benefits that could be measured			Results / findings / evidence from stakeholder consultation for each benefit			
Benefit	Activity	Hypothesis	Exist?	Meas.?	Stakeholder comments	
	<ul style="list-style-type: none"> Training asset owners / managers in use 	Use of 3D Asset Information Model allows for faster handover to FM through virtual testing of assets physically present on site.			<ul style="list-style-type: none"> Quicker handover of the as-built design information in a digital format enabling the operation of the asset <p>This benefit was estimated to be realised during handover.</p> <ul style="list-style-type: none"> Improved trust in asset information by the FM contractor helping client avoiding the costs of asset re-survey at handover. <p>This benefit was estimated to be realised during handover and is also expected to be realised on average once every 5 years (which is around the length of a typical FM contract).</p>	
9	Material savings in build and commission	<ul style="list-style-type: none"> Design reviews Design coordination & management Procurement of materials for construction 	BIM Level 2 processes including 3D, 4D and 5D modelling allows for more accurate assessment of required materials, reducing wastage on site.	Yes	No	<p>Stakeholders described that using BIM helped to reduce material waste on the project.</p> <p>This benefit was not measured because no supporting data was provided by the supply chain.</p>
10	Environmental benefit from fewer materials used	<ul style="list-style-type: none"> As a result of material savings 	Environmental benefits follow from material savings due to BIM L2.	Yes	No	<p>This benefit was not directly discussed with the stakeholders but will be the direct impact of material savings.</p> <p>This benefit was not measured because no supporting data was provided by the supply chain.</p>
11	Cost savings in asset maintenance	<ul style="list-style-type: none"> Maintenance 	Utilising an Asset Information Model allows faster access to maintenance-dependant information, saving costs during the maintenance process.	Yes	Yes	<p>Stakeholders identified the following savings in maintenance:</p> <ul style="list-style-type: none"> Reduction in cost of contract for reactive maintenance due to available asset information reducing the requirement for pre-works inspection. Undertaking regular maintenance tasks quicker due to better clash detection Annual cost savings in TOTEX (capex + opex) due to improved asset life from optimised annual maintenance activities carried out. <p>This benefits is expected to be realised in each year of asset operation.</p>
12	Cost savings in operations – facilities management	<ul style="list-style-type: none"> Develop project business case & information requirements Design authoring Handover asset and associated information to the client Asset/ building operation 	<p>Utilising Soft Landings and Asset Information Model for asset performance optimisation reduces the cost of facilities management. COBie data enables faster data transfer into CAFM.</p> <p>Utilising the 3D asset model allows better informed changes in facilities management and asset operation, and for these to be better tested before implementation.</p>	No	No	<p>BIM was not used for this purpose on the project and stakeholders did not attribute any related savings in utility bills for the asset in this project.</p>

Initial hypothesis of possible benefits that could be measured			Results / findings / evidence from stakeholder consultation for each benefit			
Benefit	Activity	Hypothesis	Exist?	Meas.?	Stakeholder comments	
13	Improved asset utilisation	• Design authoring	The use of object and design libraries has resulted in more internal floor area available for office space due to standardised arrangement of components	BIM not used as per hypothesis	No	Stakeholders mentioned that object and design libraries and Soft Landings were not used to improve asset utilisation on the project.
		• Asset / building operation	The use of Soft Landings and 3D virtual simulations ensure the asset is better suited to the end user, and is utilised as fully as possible.	BIM not used as per hypothesis	No	
		• Asset operation	The use of an Asset Information Model during the maintenance activities allows maintenance to be carried out faster.	Yes	Yes	Stakeholders identified that the AIM reduced the probability of unexpected building shutdowns due to the failure of critical equipment, as a result of the AIM providing visibility of all critical equipment. This benefit is expected to be realised to be realised on average once every 5 years over the operations period.
14	Health and Safety benefits in maintenance	• Maintenance • Health and Safety management	Using the 3D model in health and safety training improves the likelihood that maintenance will be carried out more safely.	BIM not used as per hypothesis	No	Stakeholders identified that using 3D BIM models could assist project teams in visualising health and safety risks and hazards in construction and maintenance; however, they were unable to define the information necessary for an assessment.
			Using the 3D model to inform on health and safety consultation while carrying out the design improves the likelihood that maintenance activities will be carried out more safely.			
15	Reduced variance in OPEX	• Develop project business case & information requirements	Using Soft Landings approach in combination with Asset Information Model allows for a more accurate estimation of OPEX costs from the outset of the project.	Yes	Yes	Stakeholders explained that using the AIM resulted in a more accurate asset register that allowed a reduction in the contingency included for maintenance. This benefit is expected to be realised in each year of operation.
16	Improved reputation	• Maintenance	Use of AIM helps to inform preventative maintenance needs reducing asset downtime.	Yes	No	Stakeholders identified that using the AIM for maintenance can reduce asset downtime which could positively affect the asset owner's reputation but they were unable to define the information necessary for an assessment.

B.3 Detailed valuation of estimated benefits

The following section provides quantified and monetised estimates for those benefits we measured from use of BIM Level 2 on the 39 Victoria Street refurbishment. It includes description of the impact from the use of BIM Level 2, the calculation we used to measure it, and the supporting assumptions used. All estimated benefits are stated in real present value terms, £2017, calculated over a 25 year appraisal period from the first full year of operational benefits.

B.3.1 Value of time savings in design

Estimated Benefit: £42,366

This includes time savings across the following design activities (savings accrue to various stakeholders):

1. Time savings in the design authoring activity:
 - a) Quicker updates to design documentation (including drawings) using BIM models compared to CAD based drawing.
 - b) Use of NBS product specification functionality in the BIM model reducing time to specify products compared to the manual searching and assignment of specifications to products.
 - c) Use of object libraries to save time in design detailing compared to creating the objects individually.
2. Time savings in the cost estimation of the design.

Each of these impacts are described in further detail below, including the estimated value of the benefit, the calculation used to estimate the benefit, and supporting assumptions.

Calculation applied to estimate value of benefit of time savings in design for each activity:

$$\begin{aligned}
 & \text{Value of time savings (£)} \\
 & = \text{Change in time resulting from BIM (sum of days for all stakeholders with time saving)} \\
 & \times \text{Average daily wage including overheads (£)}
 \end{aligned}$$

Value of time savings in design authoring

Estimated Benefit: £32,430

a) Time savings in design drawing updates

Estimated Benefit: £24,480

Description of impact: The creation of an object-orientated model from which conventional design drawings are created, enables design changes to be reflected in the drawings faster. This saves the manual effort of updating each drawing individually for each respective design change if traditional CAD processes are used. The stakeholders identified these time savings were realised during the on-going update of drawings associated with design development. There were also further similar savings generated from the update of section drawings that provided greater time savings per drawing.

Activity	BIM Enabler	Immediate benefit
Design authoring	BIM modelling improves accuracy of asset information and its flexibility for design changes	Quick implementation of design changes by the supply chain

Source: PwC BIM Level 2 Benefits Framework.

Supporting assumptions:

- Half hour time saving per drawing update for one architect (*excluding sectional drawings*)⁴³
- 15.5 hours of time saved per sectional drawing update for one architect ⁴⁴
- Estimated total of 325 drawings and 5 sections over design period where time is saved⁴⁵
- Cost of labour: £800/day⁴⁶

⁴³ Provided by 39 Victoria Street Design Contractor during consultation on 6th March 2018.

⁴⁴ *Ibid.*

⁴⁵ *Ibid.*

⁴⁶ Provided by 39 Victoria Street FM sub-contractor during consultation on 16th March 2018.

b) Time savings in product specification

Estimated Benefit: £4,140

Description of impact: The use of a product specification database linked to the design authoring system enables faster specification of the design. Project stakeholders identified that using the NBS database with Revit led to less time being required for tasks such as selecting an appropriate product, specifying the product in the design documentation and reviewing the specified products.

Activity	BIM Enabler	Immediate benefit
Design authoring	Creation of object and design libraries	Standard design solutions that can be used on any project

Source: PwC BIM Level 2 Benefits Framework.

Supporting assumptions:

- 40 hours saved for one architect in product specification across design process⁴⁷
- Average labour cost : £800/day⁴⁸

c) Time savings in creation of design objects

Estimated Benefit: £3,450

Description of impact: Using pre-generated BIM objects from standard object libraries enables design drawings to be completed faster. The project team used the NBS National BIM Library in Revit to model the design intent more quickly. Less time was required for stakeholders undertaking these drawing tasks.

Activity	BIM Enabler	Immediate benefit
Design authoring	Creation of object and design libraries	Standard design solutions that can be used on any project

Source: PwC BIM Level 2 Benefits Framework.

Supporting assumptions:

- 20 minutes time saved per object for one architect.⁴⁹
- 100 objects in total for design.⁵⁰
- Cost of labour: £800/day.⁵¹

Value of time savings in cost estimation

Estimated Benefit: £9,936

Description of impact: The data in the BIM model was used to generate a cost estimate by using appropriate cost estimating software and processes, saving time compared to a traditional manual process. The project team used COSTX software to automate the material quantity take-off from the BIM model, enabling faster cost estimation during the design process. Less time was taken by cost estimators and architects in the production of cost estimates.

Activity	BIM Enabler	Immediate benefit
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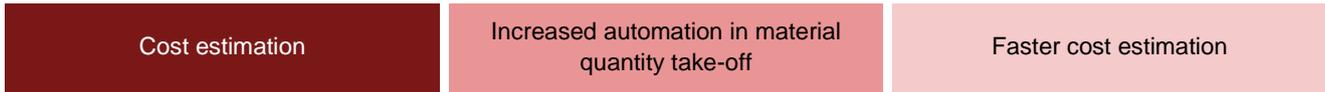
⁴⁷ Provided by 39 Victoria Street Design Contractor during consultation on 6th March 2018.

⁴⁸ Provided by 39 Victoria Street FM sub-contractor during consultation on 16th March 2018.

⁴⁹ Provided by 39 Victoria Street Design Contractor during consultation on 6th March 2018.

⁵⁰ *Ibid.*

⁵¹ Provided by 39 Victoria Street FM sub-contractor during consultation on 16th March 2018.



Source: PwC BIM Level 2 Benefits Framework.

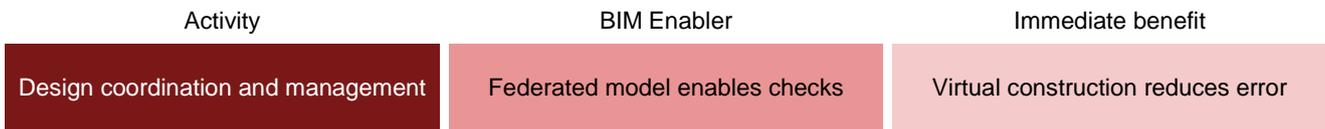
Supporting assumptions:

- 16 hours of time saved each for one architect and one cost estimator over design period.⁵²
- Average cost of labour: £800/day.⁵³

B.3.2 Time savings in build and commission

Estimated Benefit: £103,872

Description of impact: Using a federated 3D BIM model in design reviews enabled the project team to visualise and check the design better before constructing it on site which reduced the probability of construction errors on site. Stakeholders indicated that this enabled all design review attendees to save time during construction period to prepare for and undertake the design reviews compared to traditional reviews using paper drawings.



Source: PwC BIM Level 2 Benefits Framework.

Calculation of estimated benefit:

Value of time savings (£)
 = (Change in time resulting from BIM (sum of days for all stakeholders with time saving)
 × Average daily wage including overheads (£))

Supporting assumptions:

- 6 hours of time saved for each of the following stakeholders, once per week across build and commission phase: one architect, one site manager, one BIM manager, one technical services manager.⁵⁴
- Average cost of labour: £800/day.⁵⁵

B.3.3 Value of time savings in handover

Estimated Benefit: £84,520

This includes cost savings from reduction in time and thus labour cost across the following activities:

1. Asset validation survey.
2. Import of asset information into CAFM systems.

Value of time savings in asset validation survey

Estimated Benefit: £76,520

Description of impact: Use of accurate Asset Information Model populated with assets that require maintenance prevents the need for a full asset validation survey by FM contractor. In the absence of Asset

⁵² Ibid.

⁵³ Provided by 39 Victoria Street FM sub-contractor during consultation on 16th March 2018.

⁵⁴ Provided by 39 Victoria Lead Contractor and Project Manager during consultation on 28th February 2018.

⁵⁵ Provided by 39 Victoria FM sub-contractor during consultation on 16th March 2018.

Information Model, the FM contractor would send the staff to undertake the site visits to validate the assets and record their characteristics. This process would occur approximately every 5 years based on the length of the FM contract between the Department of Health and the supplier.

Calculation of estimated benefit:

Value of time savings (£) = Total cost of labour saved because asset validation survey is not undertaken.

Supporting assumptions:

- Value of time saved (total labour cost): £30,000.⁵⁶
- Saving realised during handover, and additionally will be realised on average every 5 years when new FM/Maintenance contractor appointed.

Value of time savings from import of asset information into CAFM systems

Estimated Benefit: £8,000

Description of impact: Use of Asset Information Model enabled quicker handover of up-to-date as-built information compared to updating 2D drawings and asset registers. Populating of COBie data throughout the design and construction phases enabled quicker transfer of asset information into the CAFM system compared to re-surveying the assets on site and manual entry of assets into the CAFM systems.

Activity	BIM Enabler	Immediate benefit
Handover asset and associated information to the client	AIM provides digital transfer of asset information; Soft Landings creates greater involvement of designer/contractor with client	Asset is commissioned and is in operation faster because faster input of information into systems

Source: PwC BIM Level 2 Benefits Framework

Calculation of estimated benefit:

Value of time savings (£)
= Change in time resulting from BIM (sum of days for all stakeholders with time saving)
× Average daily wage including overheads (£)

Supporting assumptions:

- 80 hour time saving combined for stakeholders involved in the transfer of information in handover.⁵⁷
- Average cost of labour: £800/day⁵⁸

B.3.4 Value of cost savings in asset maintenance

Estimated Benefit: £391,592

This includes cost savings from the following:

1. Reduction in cost of contract for reactive maintenance.
2. Undertaking regular maintenance tasks quicker due to better clash detection
3. Annual cost savings in TOTEX (capex + opex) due to improved asset life from optimised annual maintenance activities carried out.

⁵⁶ *Ibid.*

⁵⁷ Provided by 39 Victoria FM sub-contractor during consultation on 16th March 2018.

⁵⁸ *Ibid.*

Value of cost savings in reactive maintenance

Estimated Benefit: £280,255

Description of impact: Using BIM allows easier access to the information required to plan and undertake the reactive maintenance resulting in higher chance to fix the maintenance issue the first time. In the absence of accurate asset information provided by BIM, FM contractor indicated that could take multiple attempts to investigate and fix each maintenance issue resulting in additional maintenance cost. Stakeholders indicated that this could result in approximately 10% savings in the overall cost of reactive maintenance per annum.

Activity	BIM Enabler	Immediate benefit
Maintenance	AIM provides quicker access to information needed to carry out maintenance	Maintenance is carried out faster

Source: PwC BIM Level 2 Benefits Framework

Calculation of estimated benefit:

Annual cost saving (£)

$$= \text{Estimated annual cost of reactive maintenance (£) (without BIM)} \\ - \text{Estimated annual cost of reactive maintenance (£) (with BIM)}$$

Supporting assumptions:

- Maintenance contract cost per year (With BIM): £860,000⁵⁹
- Proportion of annual maintenance which is reactive (With BIM): 30%⁶⁰
- Estimated percentage saving in reactive because of BIM: 10%⁶¹

Value of cost savings in regular maintenance

Estimated Benefit: £26,946

Description of impact: Better and more holistic clash detection through the design phase would improve the consideration of access restrictions when undertaking regular maintenance tasks. Stakeholders outlined an acute example with fire dampers, where in the without BIM case they were typically positioned in areas where access is challenging. This then requires either the use of access platforms and / or removing other M&E equipment to access the fire dampers. All fire dampers in the building require inspection on an annual basis and there are numerous dampers in the building.

Activity	BIM Enabler	Immediate benefit
Maintenance	AIM provides quicker access to information needed to carry out maintenance	Maintenance is carried out faster

Source: PwC BIM Level 2 Benefits Framework

Calculation of estimated benefit:

$$\text{Annual cost savings in regular maintenance of fire dampers due to better clash detection in design (£) =} \\ \text{Maintenance time saved due to BIM (hours)} \times \\ \text{Average cost (time and materials) of maintenance per hour (£)}$$

Supporting assumptions:

⁵⁹ Provided by 39 Victoria Street Client (Department of Health) on 22nd March 2018.

⁶⁰ Provided by 39 Victoria Street FM sub-contractor during consultation on 16th March 2018.

⁶¹ *Ibid.*

- 35 hours of time saved for two maintenance contractors each per annum (70 labour hours in total).⁶²
- Labour cost for one maintenance worker: £30/ hour⁶³

Value of cost savings from optimised whole of life maintenance spend due to improved life span of the asset

Estimated Benefit: £84,390

Description of impact: Using an Asset Information Model for development and planning of maintenance allows timing and amount of maintenance undertaken to be optimised over the whole life of the asset. Stakeholders indicated that in their experience when BIM is not used, for buildings / fit outs similar to that of 39 Victoria Street, 20-30% of non-statutory planned maintenance is usually ‘value engineered’ out due to asset owner annual budget constraints and an inability to easily optimise total spending on planned maintenance over the lifetime of the asset. In their experience this leads to a reduction in asset life of between 15 and 20%. Effectively, this means that when using BIM, the overall annual cost of non-statutory planned maintenance can be higher, but because replacement of asset components is required less frequently, on a whole-of-life basis, annualised TOTEX (Capex + Opex) is lower, resulting in cost savings over the life of the asset.

Activity	BIM Enabler	Immediate benefit
Maintenance	AIM provides better information to inform strategic maintenance planning	Maintenance is carried out more efficiently

Calculation of estimated benefit: We applied the below assumptions to calculate the estimated annual saving in TOTEX on a present value basis for 39 Victoria Street based on stakeholder description of the impact above. These savings are considered additional to those calculated above for reactive and regular maintenance.

Supporting assumptions:

- Capital cost of refurbishment (design and construction): £12,815,000 (December £2015).⁶⁴
- Average expected life of asset components with BIM: 25 years.⁶⁵
- Average expected life of components without BIM: 20 years.⁶⁶
- Annual total maintenance cost (WITH BIM): £860,000.⁶⁷
- Percentage of planned maintenance that is non-statutory: 65%.⁶⁸
- Assumed % of planned maintenance not carried out when BIM is not used (value engineered out): 25%⁶⁹

B.3.5 Value of cost savings in refurbishment

Estimated Benefit: £23,463

Description of impact: Using an Asset Information Model while carrying out refurbishment tasks makes carrying out design changes post-commissioning easier and faster. A fully coordinated 3D model reduces the input traditionally required from a design team, and ensures updates to the asset are adequately spaceproofed and clash detected before work is carried out on site.

Activity	BIM Enabler	Immediate benefit
Refurbishments and upgrades	AIM provides quicker access to accurate asset information	Reduced need and cost for re-survey to support refurbishment design

⁶² Provided by 39 Victoria Street FM sub-contractor during consultation on 16th March 2018.

⁶³ *Ibid.*

⁶⁴ Provided by 39 Victoria Street Project Manager on 22nd March 2018.

⁶⁵ Provided by 39 Victoria Street FM sub-contractor during consultation on 16th March 2018.

⁶⁶ *Ibid.*

⁶⁷ Provided by DOH stakeholder on 22nd March 2018.

⁶⁸ Provided by 39 Victoria Street FM sub-contractor during consultation on 16th March 2018.

⁶⁹ *Ibid.*

Source: PwC BIM Level 2 Benefits Framework

Calculation of estimated benefit:

Annual cost savings from fewer changes required during refurbishments (£)
 = *Time saved in implementing changes (hours) × Number of stakeholders*
 × *Average labour cost of stakeholders (£/hour)*

Supporting assumptions:

- 24 hours saved per annum by design team members in making changes during minor refurbishments.⁷⁰
- Average labour cost for design team members: £800/ day⁷¹

B.3.6 Reduced variance in Operating Expenditure

Estimated Benefit: £2,943

Description of impact: The AIM and COBie data provided as part of the handover documentation provided the FM contractor with more confidence in the accuracy of the asset register. This asset register informed the cost estimates for the O&M activity and hence the more accurate register reduced the risk associated with predicting future operational costs. The FM contractor estimated that this resulted in a 10% reduction in the associated risk allowance.

Activity	BIM Enabler	Immediate benefit
Develop project business case & information requirements	Soft Landings requires definition of business and operational performance outcomes at the outset, project stakeholders are engaged from the outset.	Better defined OPEX costs in contracts

Source: PwC BIM Level 2 Benefits Framework

Calculation of estimated benefit:

Value of reduced risk per annum (£)
 = *Reduction in contingency held (£) × Opportunity cost of holding contingency*
 Where: *reduction in contingency held (£) = % reduction in contingency × annual OPEX (£)*

Supporting assumptions:

- Contingency held by FM Contractor (without BIM) = 10% of annual maintenance contract.⁷²
- Reduction in total amount of contingency held by FM Contractor (with BIM): 10%.⁷³
- Opportunity cost of holding capital: 3.5%⁷⁴

B.3.7 Improved asset utilisation

Estimated Benefit: £28,151

Description of impact: The probability of a building shutdown is reduced due to BIM data (in the AIM and COBie) providing a more holistic and accurate asset register that informs FM activity. This improved ability to understand the condition of critical equipment reduces the probability of the loss of output associated by an unscheduled building shutdown. Stakeholders provided details of likelihood and impact of such a shutdown

⁷⁰ Provided by 39 Victoria Street FM sub-contractor during consultation on 16th March 2018.

⁷¹ *Ibid.*

⁷² *Ibid.*

⁷³ *Ibid.*

⁷⁴ The opportunity cost of holding contingency is valued (from the point of view of UK society) using the social rate of time preference as expressed in the Green Book; 3.5% per annum.

with and without BIM based on their professional expertise and experience of actual events at a very similar building to 39 Victoria Street.

Activity	BIM Enabler	Immediate benefit
Asset / building operation	3D model enables virtual simulation processes (less prone to error); Soft Landings supports continued client education	Reduced time taken to execute space changes, better decisions made about asset operation

Source: PwC BIM Level 2 Benefits Framework

Calculation of estimated benefit:

Value of improved asset utilisation due to reduced risk of shut down(£)
 = *Reduction in probability of shutdown*
 × *(loss of output per person as measured by average hourly wage per person (£))*
 × *number of people affected × time taken to resolve the shutdown(hours))*

Supporting assumptions:

- Probability of shutdown occurring once in five year period without BIM is 10 %⁷⁵
- Probability of shutdown occurring with BIM once in 5 year period is .1 %⁷⁶
- Estimated average time taken to resolve a shutdown: 4 hours.⁷⁷
- Number of people affected by shutdown: 1000.⁷⁸
- Average daily wage of DoH personnel: £231/day.⁷⁹

⁷⁵ Provided by 39 Victoria Street FM sub-contractor during consultation on 16th March 2018

⁷⁶ Provided by 39 Victoria Street FM sub-contractor during consultation on 16th March 2018

⁷⁷ Provided by 39 Victoria Street FM sub-contractor during consultation on 16th March 2018

⁷⁸ Provided by DOH stakeholder during consultation on 22nd March 2018.

⁷⁹ Provided by DOH stakeholder during consultation on 22nd March 2018.

Appendix C: Foss Barrier - Detailed activities, findings and benefit estimates

This section provides quantified and monetised estimates for those benefits we measured from use of BIM Level 2 on the Foss Barrier Upgrade. It includes description of the impact from use of BIM Level 2, the calculation we used to measure it, and the supporting assumptions used.

C.1 Our application of the BMM

Table 9 shows the steps (linked to those described in Figure 1) we took to identify, prioritise, and measure potential benefits arising from the use of BIM Level 2 on the Foss Barrier project. It provides a description of the detailed activities undertaken and the results and outcomes achieved. It also incorporates the 'stage gates' from our agreed scope of work, and a description of status or progress for each.

Table 9: Application of the BMM to the Foss Barrier Upgrade.

Step (from Figure 1)	Detailed activities undertaken	Results / outcomes achieved
2. Initial assessment of benefits to be measured	<ol style="list-style-type: none"> Initial consultation with Foss Barrier Project Manager (Environment Agency National Capital Programme Management Service) to understand the nature of the Foss Barrier Upgrade, how BIM Level 2 was used on the upgrade, and his view on what benefits (from the BMM Framework) were as a consequence likely to have been realised (up to the 'build and commission' phase) and those that may be realised in the future (following the 'build and commission' phase) Reviewed the following documents relating to the Upgrade, provided by Environment Agency: <i>Foss Barrier Recovery Project Short Form Business Case</i> (14/12/2016); Information delivery plan Foss Barrier Recovery Works (18/08/2016); CH2M, <i>Project BIM Execution Plan WEM Lot 3 Foss Barrier Par</i> (March 2016). Developed a list of potential benefits on which to focus the measurement effort. Further consultation undertaken with Environment Agency FCRM Manager to confirm likelihood and extent of potential 'future' benefits based on Environment Agency plans for collecting and using the 'as-built' asset information for the Barrier. 	<p>Based on the emergency nature of the upgrade work, and the immature application of BIM (relative to full level 2 compliance), the list of benefits prioritised for further testing and attempted measurement was short but focused. It included:</p> <ol style="list-style-type: none"> A list of 5 benefits of 'primary focus' reported to be potentially material in the 'design' and 'build and commission' phases of the project. A list of potential 'future' benefits that may be realised once the upgraded Barrier moves into operational phase, depending upon future Environment Agency action in collecting and using digital as-built asset information for the Barrier. List discussed and augmented with Environment Agency FCRM Manager.
<p>Stage Gate 1: Passed. Recommendation to proceed with attempted measurement of benefits. While the list of potential benefits in design and build and commission was not extensive due to the relative BIM immaturity of the project, these were augmented with potential benefits in operational phase. Foss Barrier Project Manager was able to facilitate engagement with supply chain (although this was slightly delayed due to project commitments). Environment Agency staff also accessible and able/willing to engage. Good chance established of measuring at least 3 benefit types (from the BMM Framework). Critical success factors met and agreement to proceed obtained.</p>		
3. Detailed consultations with client and supply chain	<ol style="list-style-type: none"> Conducted workshop with Foss Barrier Project Manager and representatives from Environment Agency's design and construction supply chain to obtain input on the size of the benefits on the list of 'primary focus', and relevant information to support measurement of these benefits. This involved detailed discussion of how BIM was used at each stage of the asset lifecycle (up to and including 'build and commission'). It incorporated discussion of how design and construction would have been undertaken differently if BIM was not used, and comparison of each approach to understand the estimated differences in resources required, and outcomes achieved. Impact pathways from the BMM framework used to support discussion. Further consultations undertaken with Environment Agency National Mechanical and Engineering Lead, and Environment Agency Regional Mechanical and Engineering team to understand and collect data to support possible measurement of benefits in operations. 	<ul style="list-style-type: none"> Initial list of potential benefits to measure in 'design', 'build and commission', and 'handover' narrowed: <ul style="list-style-type: none"> 3 benefit types prioritised for measurement; expected size of each benefit to be measured smaller than initial expectations. 2 benefit types de-prioritised due to stakeholder assessment that BIM Level 2 had no material impact.

Step (from Figure 1)	Detailed activities undertaken	Results / outcomes achieved
		<ul style="list-style-type: none"> • Initial list of potential benefits for measurement in 'operation' narrowed: <ul style="list-style-type: none"> - 1 benefit type prioritised for measurement - 3 benefit types de-prioritised due to lack of evidence or materiality. <p><i>(See Section 2.4 for detailed results from stakeholder consultation).</i></p>
4. Collect outstanding data and undertake measurement	<ol style="list-style-type: none"> 1. Summarised findings from workshop discussion with Environment Agency Foss Barrier Project Manager and Supply chain sent to stakeholders for review and confirmation, including list of supporting data requested as inputs to estimate quantified benefits. 2. Requested Foss Barrier Project Manager and supply chain completion of BIM Maturity Assessment Tool (BMAT) for the Barrier Upgrade. 3. Data received from stakeholders, including completed BMAT, and outstanding questions confirmed. 4. Developed/calculated quantified and monetised estimate of each benefit on net present value basis according to approach described in BMM, using data provided by stakeholders and publically available information as supporting assumptions (e.g. ONS wage data). 5. Further follow up consultation with stakeholders undertaken to test / confirm assumptions underpinning estimated benefit calculations. 	<ul style="list-style-type: none"> • Quantified and monetised estimates for four benefit types (see Section 2.5 for detailed estimates). • Qualitative explanation of benefits identified but unable to be quantified (see Section 2.4 for explanation).
5. Develop benefits report	<p>Write chapter of report containing details for Foss Barrier Upgrade (Chapter 3) including:</p> <ul style="list-style-type: none"> - Summary of Barrier Upgrade project (Section 3.1) - Explanation of how BIM was used (Section 3.2) - Detailed description of how we applied the BMM to identify, prioritise, and measure potential benefits; and what results were achieved (Section 3.3 – this section) - Discussion of all potential benefits identified and which ones proceeded to measurement stage (Section 3.3) - Quantified and monetised estimate of each benefit measured (Section 3.5) <p>Document lessons learnt and critical assessment of results from application of BMM to Foss Barrier Upgrade (see Chapter 4).</p>	<p>Draft benefits report provided to Innovate UK 26 March 2018 including all details relating to application of the BMM to the Environment Agency's Foss Barrier Upgrade.</p>

C.2 Findings from stakeholder consultation

The application of the BMM resulted in the identification and calculation of 4 benefit categories on the Foss Barrier Upgrade. A number of additional possible benefits were each discussed with various stakeholders as part of the consultation process, however not all of them could be estimated quantitatively.

Table 10 shows in detail each of the potential benefits (derived from the benefits framework) that we tested with stakeholders during consultation, and the evidence collected about each one. It provides the details of the initial hypothesis for the existence of each benefit (based on early consultation and document review), and shows our assessment of whether the benefit is likely to exist on the Foss Barrier Upgrade. Assessment is based on stakeholder comments and evidence provided. The table also shows which benefits we were able to measure based on the information provided, and which we were not and why. Detailed benefit estimates are provided in Appendix C, Section 3.

Table 10: Results of testing potential benefits for measurement with stakeholders

Initial hypothesis of possible benefits that could be measured			Results / findings / evidence from stakeholder consultation for each benefit			
Benefit	Activity	Hypothesis	Exist?	Meas.?	Stakeholder comments	
Benefits of Primary Focus (Design to Handover stages)						
1	Time savings in design	• Design Authoring	Use of 3D modelling (across various design activities) reduces the time taken to carry out the design	No	No	Stakeholders were unable to confirm any material net time savings due to the level and nature of BIM Level 2 application in Design Authoring.
		• Client review and stakeholder consultation • Design reviews • Design coordination and management		Yes	Yes	As a top down high level estimate, design team stakeholders estimate possible 5% efficiency savings for design team across design process. Stakeholders also described further time savings (for the client and construction contractor) in undertaking each design review. However, it was unclear whether there would be net savings across the design process overall, as it is likely that fewer design reviews would have been undertaken if BIM was not used, and hence the net impact on time saved could not be clearly defined. It is likely that using BIM in design review would also result in additional savings from better clash detection, fewer changes required, and/or benefits from a better quality asset for the end user. Stakeholders were unable to define the information necessary for assessment of these associated impacts, hence any further impact on time savings in design reviews beyond overall 5% design team efficiency savings have not been quantified as part of our estimate.
2	Time savings in build and commission	• Design reviews • Design coordination and management	Use of 3D modelling (across various activities in design and build/commissioning) reduces the time taken to carry out construction and commissioning	Yes	No	Design and Build and Commission undertaken in parallel. We have therefore included measurement of these savings as part of time savings in design for simplicity and to avoid double counting.
		• Site layout and logistics planning		BIM not used as per hypothesis	No	BIM model not used for these purposes.
		• Construction schedule planning		Yes	Yes (Section 2.5.2)	Small amount of time saved by the construction team in planning schedule with BIM L2.
		• Health and Safety Management • Site Inductions		BIM not used as per hypothesis	No	BIM model not used for these purposes.

Initial hypothesis of possible benefits that could be measured			Results / findings / evidence from stakeholder consultation for each benefit			
Benefit	Activity	Hypothesis	Exist?	Meas.?	Stakeholder comments	
3	Cost savings from better clash detection	<ul style="list-style-type: none"> Design coordination and management 	Clashes are detected virtually using a federated model rather than during site activities, leading to less wastage of time and materials (costs)	Yes	Partial	<p>Stakeholders indicated that application of BIM L2 did result in cost savings in clash detection because use of the 3D model allowed clashes to be identified digitally, allowing zero clash problems on site.</p> <p>Stakeholders were unable to define the information necessary for a quantified assessment. They said it was not possible to establish a likely counterfactual scenario in the 'without BIM L2' case because it was too hypothetical in nature to 'guess' what clashes could have happened on-site if BIM L2 was not used.</p> <p>Clash detection was run once a week on the project. Identifying a counterfactual could be done by running through weekly clash reports (average clash report has around 700 lines of data), and making a value judgement on whether the clash would have been identified in a without-BIM L2 scenario, and then making assumptions to estimate the possible negative impact (cost) of those clashes that would likely not have been picked up without BIM L2. Stakeholders agreed this was possible but would be incredibly resource intensive in retrospect, and it was unlikely that recollection would be accurate enough to remember enough details about the clashes reported. Stakeholders agreed that if the project had been set up to capture this information from the outset it would have been possible to estimate.</p> <p>One example of a clash detected through use of BIM L2 (which would have been unlikely to be picked up without BIM L2) was provided. Construction contractor provided details of the avoided costs in time and materials to support measurement of the estimated benefit.</p>
4	Cost savings from fewer changes	<ul style="list-style-type: none"> Client review and stakeholder consultation 	Required design changes are identified virtually resulting in less rework on site	BIM not used as per hypothesis	No	<p>Stakeholders indicated BIM L2 was not a key use as part of client and stakeholder review, and therefore unlikely to have a material impact.</p> <p>As there was only a very small team, all working together on site-BIM L2 was not used materially in the change control process.</p> <p>Stakeholders agreed that this could be a potentially larger benefit on a project with a bigger site or more stakeholders.</p> <p>Stakeholders did indicate there were time savings in the design process to make changes in general. These savings are captured and measured as part of 'times savings in design', and are not measured further here so as to avoid double counting.</p>
5	Time savings in handover	<ul style="list-style-type: none"> Test assets Train asset owners / managers in use Handover asset and associated information to client. 	Digital transfer of accurate as-built asset information and using the Asset Information Model (AIM) for testing and training saves time in the handover phase	BIM not used as per hypothesis	No	<p>Stakeholders indicated that time savings in handover will not exist as the as-built asset information will need to be collected manually and input into Environment Agency systems.</p> <p>Stakeholders indicated possible time savings in training asset owners in use of the asset, but indicated these were likely to be very small / immaterial in the handover phase and have therefore not been quantified.</p>
Potential benefits of secondary focus Design to Handover stage (from initial discussions these were unlikely to be material)						
6	Improved Health and Safety (during construction)	<ul style="list-style-type: none"> Design reviews Health and safety management 	Using 3D/4D modelling to address potential site hazards, and to inform training, reduces the risk of H&S incidents on site	BIM not used as per hypothesis	No	Stakeholders confirmed BIM model not used for health and safety training and unlikely to have had any material impact on site hazards.

Initial hypothesis of possible benefits that could be measured			Results / findings / evidence from stakeholder consultation for each benefit			
Benefit	Activity	Hypothesis	Exist?	Meas.?	Stakeholder comments	
7	Material Savings in Build and Commission Environmental benefit from fewer materials used	Multiple activities	3D/4D modelling allows for more accurate assessment of required materials, reducing wastage on site	No	No	Stakeholders confirmed that use of BIM L2 was unlikely to have had any material impact on reducing wastage on site, beyond any impact through better clash detection. Insufficient stakeholder identification of materials savings means corresponding environmental benefits not material.
Possible Benefits in Operation						
8	Time savings in incident response	Incident management	Faster access to accurate information through the use of AIM to manage an incident, reduces the time required for coordinating incident response	Yes	No	As part of stakeholder consultation, we spoke to Environment Agency employees who responded to the incident on Boxing Day 2015 at the Barrier. Both stakeholders independently stated that having access to faster accurate information through an AIM would not have reduced the time required to coordinate and manage response to the incident, or would have improved their ability to respond. They both stated that in the case of a different incident, faster, more accurate information could have improved incident response, especially if responders were not familiar with the Barrier. However, in this particular case, as the Barrier was completely submerged in water they did not believe an AIM would have had any material impact.
9	Cost savings in asset maintenance	Maintenance	Asset Information Models allow quicker access to better information, and increases the efficiency of asset maintenance	Yes	Yes	As a top down high level estimate, Environment Agency's National Mechanical and Electrical Maintenance Lead estimated that use of an AIM with as-built asset information could result in 6-7% per annum savings in total maintenance costs – both from savings in Environment Agency staff time planning maintenance, and in savings from maintenance contractors getting things fixed right the first time. The Foss Barrier Mechanical and Electrical maintenance team agreed there would likely be savings in both their time and contractors time from having an AIM with as-built asset information. Because they were not familiar with BIM or how such a model would work, they could not provide a quantified estimate of likely time/cost savings.
10	Health and Safety benefits in maintenance	Maintenance	Using 3D/4D modelling to address potential site hazards, and to inform training, reduces the risk of H&S incidents on site	Yes	No	Stakeholders indicated possible benefits but stated they were unlikely to be material as there were no incidents on-site to their knowledge that had caused negative impacts when maintenance was being carried out.
11	Improved reputation	N/A	If use of BIM resulted in reduction in the overall time schedule required to complete the project this could result in further reputational benefits to Environment Agency than otherwise.	Hypothesis could not be confirmed.	No	Stakeholders were unable to confirm or deny whether the overall project time schedule would have been longer without the use of BIM Level 2.

C.3 Detailed valuation of estimated benefits

The following section provides quantified and monetised estimates for those benefits we measured from use of BIM Level 2 on the Foss Barrier project. It includes description of the impact from the use of BIM Level 2, the calculation we used to measure it, and the supporting assumptions used. All estimated benefits are stated in real present value terms, £2017, calculated over a 25 year appraisal period from the first full year of operational benefits.

C.3.1 Value of time savings in Design

Estimated Benefit: £132,317

Description of impact: During consultation Environment Agency Design Contractor stakeholder identified that use of BIM across multiple activities in the design process of the Barrier Upgrade could have resulted in approximately 5% efficiency saving across the overall design process for the design contractor, of 26 months from April 2016 to September 2018.⁸⁰ This was due predominantly due to reduction in abortive design work required, and also includes time savings from easier/quicker access to accurate data due to BIM naming conventions in design coordination and management.

Calculation of estimated benefit:

$$\text{Value of time savings (£)} = \frac{\text{(Cost of design to EA)}}{(1 - \text{efficiency savings (\%)} \text{ from use of BIM})}$$

Supporting assumptions:

- Cost of design phase: £2.5 million.⁸¹

C.3.2 Value of time savings in Build and Commission

Estimated Benefit: £5,757

Description of impact: Environment Agency's Construction contractor stakeholders indicated that using combined 3D federated models and project schedules for sequence planning, and 4D management of lean construction led to time savings in the 'build and commission' phase for the construction team. These digital tools allowed the construction team to understand and implement the construction sequence more quickly.

Activity	BIM Enabler	Immediate benefit
Construction schedule planning	Use of combined 3D federated models and project schedules for sequence planning, 4D management of lean construction	Easier understanding of construction sequence by supply chain

Source: PwC BIM Level 2 Benefits Framework

Calculation of estimated benefit:

⁸⁰ Provided by Stakeholders during consultation with Environment Agency project manager, Design contractor, and Construction contractor on 20th February 2018

⁸¹ Provided by Stakeholders during consultation with Environment Agency project manager, Design contractor, and Construction contractor on 20th February 2018

Value of time savings (£)

*= Change in time resulting from BIM (sum of days for all stakeholders with time saving)
× Average daily wage including overheads (£)*

Supporting assumptions:

- 8 FTE days saved in total at beginning of build and commission phase across senior project stakeholders including Environment Agency project manager and one additional senior Environment Agency staff member; civil engineer and director (from the construction contractor); and one lead structural engineer, one director, and one architect (from design contractor).⁸²
- Average daily labour cost derived using costs reported by 39 Victoria Street stakeholders. We used ASHE data on wages in a sample of 52 occupations in the construction and government sector to calculate the London-Yorkshire wage differential. Using this, London wages were scaled down to reflect difference in nominal wages (2017 prices) between the two and calculate an approximate labour cost for Foss Barrier contractors.

C.3.3 Value of cost savings from better clash detection

Estimated Benefit: £6,500

Description of Impact and supporting pathways from PwC Benefits Framework: During consultation, stakeholders from Environment Agency, the design team, and the construction team indicated that using 3D federated models led to a reduction in the number of clashes detected onsite. Stakeholders were not able to provide estimates of the overall number or impact of clashes that would not have not been detected in design if 3D federated models were not used, and 2D drawings had instead been used.⁸³ They did provide one concrete example of where a clash was detected using BIM Level 2, which would not likely have been picked up until on-site construction, if BIM Level 2 was not used. This would have caused additional costs in time, materials, and transport to be incurred. The specific case was of a solid copper bus duct that through the BIM model, was identified to be the wrong size, and would not fit into the space available. If this had not been identified, it would have required a new, modified bus duct to be ordered from The Czech Republic, resulting in added costs from time, materials, and transport.

Activity	BIM Enabler	Immediate benefit
Design coordination & management	Federated model enables checks	Automated clash detection reduces rework during construction (leading to time savings)
Design coordination & management	Federated model enables checks	Automated clash detection reduces rework during construction (leading to material savings)

Source: PwC BIM Level 2 Benefits Framework

Calculation of estimated benefit:

Cost saving from example of clash detection provided (£)

*= Cost of materials (bus duct section, hiring of scaffold) (£)
+ Transport costs frm Czech Republic (£) + Labour costs on installation (£)
– Approximate cost of fixing clash in design (£)*

Supporting assumptions:⁸⁴

- Costs that would have been incurred to reorder and install the correct bus duct (without BIM case):

⁸² Provided by Stakeholders during consultation with Environment Agency project manager, Design contractor, and Construction contractor on 20th February 2018

⁸³ See Section C.2.

⁸⁴ Provided by Environment Agency Construction contractor, assumed December 2017 prices.

- Materials cost for new bus duct section: £3,000
 - Transport costs from Czech republic: £500
 - Labour costs of installation (2 contractors x 2 days each): £2,400
 - Extended hire of scaffold: £600
- Cost of fixing clash in design approximated at zero.

C.3.4 Value of potential future cost savings in asset maintenance

Estimated Annual benefit: £223,118

Description of impact and supporting pathways from PwC Benefits Framework: Using an as-built asset information model of the Barrier is estimated to lead to 6-7% savings in annual maintenance costs, based on consultation with the Environment Agency's National Mechanical and Electrical Engineering lead. This includes savings in both Environment Agency staff time to plan and predict annual maintenance planning, and in time to undertake maintenance on-site by contractors (which is therefore likely to decrease the cost of overall maintenance contract value by this amount).

Activity	BIM Enabler	Immediate benefit
Maintenance	AIM provides quicker access to info needed to carry out maintenance	Maintenance is carried out faster
	AIM provides better info to inform strategic maintenance planning	Maintenance is carried out more efficiently (with greater potential for preventative maintenance (leading to time savings in maintenance))

Source: PwC BIM Level 2 Benefits Framework

Calculation of estimated benefit:

$$\begin{aligned}
 & \text{Value of annual cost savings (£)} \\
 & = \text{Estimated increased efficiency from using AIM for maintenance planning and execution (\%)} \\
 & \quad \times (\text{Average annual maintenance contract cost}) (\text{£}) \\
 & \quad + \text{Annual labour cost of EA Maintenance planning staff (£)}
 \end{aligned}$$

Supporting assumptions:

- Estimated annual contract cost of maintenance for Foss Barrier (includes planned, reactive, and emergency): £200,000⁸⁵
- Increased efficiency of maintenance applied = 6.5%⁸⁶
- Number of Environment Agency FTE required for maintenance at Foss Barrier = 0.4⁸⁷
- Average annual labour cost of Environment Agency maintenance staff per FTE is derived from ASHE data on wages of engineering technicians in Yorkshire.⁸⁸

⁸⁵ High level estimate (given annual maintenance budgets for Upgraded Barrier not yet established) provided by Environment Agency MEICA Maintenance Team with responsibility for the Foss Barrier during consultation on 21st March 2018.

⁸⁶ *Ibid.*

⁸⁷ *Ibid.*

⁸⁸ <https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/earningsandworkinghours/datasets/regionbyoccupation4digitsoc2010ashtable15>

Appendix D: Detailed economic assumptions

In addition to the detailed assumptions provided in Appendixes C and D for each benefit estimate, we have used the following general assumptions in estimating the economic benefits in this report:

- **Discount rate** of 3.5% per annum used to calculate Net Present Value of benefits over the appraisal period. We use the Social Time Preference Rate (STPR) which is the real discount rate as per Green Book Guidance. ⁸⁹Discounting allows us to understand the value of the stream of benefits and is based on the assumption that people prefer to receive benefits now than in the future. ⁹⁰
- An **overhead rate** of 30% is used to convert wages to total labour costs. Total Labour Cost = Wage + Overhead costs. The overhead rate incorporates costs in addition to direct labour costs such as Employer's National Insurance Contributions, sick pay, and fixed administration costs. We use the rate from the UK Standard Cost Model⁹¹.
- The **opportunity cost of holding capital** is the value which reflects the best alternative use it could be put to if it were not tied up. For government construction clients, the opportunity cost of holding can be approximated as the social rate of time preference as in the Green Book at 3.5% per annum. ⁹²
- Where stakeholders have provided assumptions regarding **cost of labour and hours worked per day** we have used these as the central assumptions in our analysis. If this information isn't provided by stakeholders, we use hours worked per week and per day from ONS data.⁹³
- London **labour costs** are scaled down by a factor of 1.2 to estimate analogous labour costs for the Foss Barrier Upgrade, which is in Yorkshire. The scaling factor is based on an estimate of the London wage premium for occupations in the construction industry. This was calculated using median wages in London and Yorkshire from ASHE Data published by the Office of National Statistics. ⁹⁴
- All **price data is converted to £2017 prices**, using annual GDP deflator series published by ONS.⁹⁵
- As a **measure of output lost** due to asset shutdown in the case of the Department of Health (DoH) building, we use average wages of DoH personnel as provided by the 39 Victoria Street FM sub-contractor team members. In economic theory, one more worker is hired until the cost to the employer (wage) is equal to the output produced by that worker i.e. the **wage is equal to the marginal product of labour**. This assumption is true even when labour markets aren't perfectly competitive.

⁸⁹ https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/685903/The_Green_Book.pdf

⁹⁰ https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/685903/The_Green_Book.pdf

⁹¹ <http://regulatoryreform.com/wp-content/uploads/2015/02/UK-Standard-Cost-Model-handbook.pdf>

⁹² In particular, the Green book says that private costs, particularly regulatory costs must also be discounted at the Social Time Preference rate (STPR). This rate is currently at 3.5%

⁹³ <https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/earningsandworkinghours/datasets/averagehoursworkedbyindustryhour03>

⁹⁴ <https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/earningsandworkinghours/datasets/regionbyoccupation4digitsoc2010ashtable15>

⁹⁵ <https://www.ons.gov.uk/file?uri=/economy/grossdomesticproductgdp/datasets/ukquarterlynationalaccountsdatatables/current/ukquarterlynationalaccountsdatatables.xls>

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