Improving Health and Safety Outcomes in Construction
Making the Case for Building Information Modelling (BIM)
Acknowledgements

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Cover image: An engineering construction model developed for National Grid by consultants Premtech. Initially used for design and construction, this model is now animated and used in a virtual reality environment for training engineers to undertake maintenance tasks safely.

Case study 1 appears courtesy of the Environment Agency
Case study 2 appears courtesy of National Grid
Case study 3 appears courtesy of Highways England and Balfour Beatty VINCI JV
Case study 4 appears courtesy of Transport for London
Case study 5 appears courtesy of National Grid
Case study 6 appears courtesy of North Midland Construction PLC.
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Case study 8 appears courtesy of Transport for London and Mott MacDonald
Case study 9 appears courtesy of Highways England and Skanska / Balfour Beatty JV
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Improving Health and Safety Outcomes in Construction

Making the Case for Building Information Modelling (BIM)

In 2011, the UK government published its Construction Strategy (GCS 2011-15), which aimed to reduce the cost of public sector assets by 20%, while achieving a significant positive change in the relationship between public authorities and the construction industry, and ensuring that the Government is able to produce lasting social and economic infrastructure at a reasonable cost.

One means of achieving this was through the development of standards enabling all members of the supply chain to work collaboratively through Building Information Modelling (BIM) and a requirement for fully collaborative 3D BIM (Level 2) on all Government-funded projects by April 2016.

“Government as a client can derive significant improvements in cost, value and carbon performance through the use of open sharable asset information.”

http://www.bimtaskgroup.org/bim-faqs/

Although this strategy is aimed at delivering the majority of the 20% saving through a reduction of capital expenditure (CapEx) costs, it is acknowledged that there is much more that can be realised through the adoption of the BIM methodology and associated tools, particularly with regards to the operational stages of the project lifecycle.

Building Information Modelling and Health and Safety Outcomes

Around 2.2 million people work in the construction sector, representing around 7% of the GB workforce. It contributes around £97 billion to the economy, equivalent to around 6% of the total GDP. However, construction remains one of the most hazardous industries, accounting for about a quarter of all GB fatal injuries to workers. In the five years to March 2016, 210 construction workers have died and many more have received life-changing injuries at work. The sector has a statistically significantly higher rate of occupational lung disease and musculoskeletal disorders than the average for all industries.

Health and Safety Executive’s (HSE) Construction Division believes that measurable benefits could be brought to the construction and post-occupancy management of assets (buildings and infrastructure) through the increased use of the BIM methodologies, improving health and safety outcomes in the construction sector and ‘Helping Great Britain work well’.

To this end, the BIM 4 Health & Safety Working Group was established in 2015 by HSE Construction Division, with the aim of investigating the possibility of improving health and safety outcomes through...
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the use of BIM, and to share information about hazards and risks. The purpose of this white paper is to illustrate the relationship between BIM and health and safety outcomes, and to bring to life the benefits of BIM in practice through illustrated examples from across industry, as well as outlining the challenges and the limitations of the BIM approach.

What is Building Information Modelling?

Building Information Modelling (BIM) supports the digitisation of construction and uses information relating to the assets to build a three dimensional model with supporting intelligent, structured data attached to them. It is a way of working underpinned by digital technologies to unlock more efficient methods of designing, creating and maintaining assets. The information contained within the models facilitates better decision making, resulting in better business outcomes, improved communication, and enables de-risking of construction activities; all of which leads to improvements in efficiency.

The BIM Maturity Model

The BIM Maturity model, shown in Figure 1, provides a strategic road map for the development of BIM within construction projects. Presented visually as the ‘BIM wedge’, each of the levels reflects the increasing ability of the supply chain to collaborate and exchange information both within and across projects and highlights the current data management standards, guides and classification systems that facilitate the sharing of information.

The lowest level of maturity and the simplest form of BIM is Level 0 which relies predominantly on paper based systems and unmanaged CAD (Computer Aided Design). The next level (1) has managed CAD in 2D or 3D formats. Level 2 involves developing building information in a collaborative 3D environment with data attached, but created in separate discipline models. Level 3 is a fully integrated process with a single, online, shared model. Government has set the target of Level 2 as the minimum standard for all publically funded construction projects.

![Figure 1 The BIM “Wedge” (© Bew and Richards 2008)](image-url)
Building Information Modelling throughout the asset life cycle

The Specification for information management for the capital / delivery phase of construction projects using building information modelling (PAS 1192-2) provides the framework for collaborative working and information management in a BIM Level 2 environment. Within this environment, contributors are asked to produce information using defined standards and methods to ensure the quality of the information produced. The information delivery cycle involves collecting data in such a way that it can be shared and used without the need to reinterpret its meaning as it moves through the project lifecycle and is eventually pulled together into a health and safety file. This process is detailed in Figure 2 and focuses specifically on project delivery, where the majority of graphical data, non-graphical data and documents, known collectively as the project information model (PIM), are accumulated from design and construction activities.

Figure 2 The information delivery cycle (PAS 1192-2 ISO, 2013)

It shows, in blue, the generic process of identifying the project requirements, procuring and awarding a contract, mobilising a supplier and generating production information and asset information relevant to the need. This cycle is followed for every aspect of a project, including the refinement of design information through procurement, design, construction, delivery, operation and maintenance of buildings and infrastructure assets, which are shown in green, and represent the information delivery process known as the common data environment (CDE).

Information management through a common data environment (CDE)

Essentially, BIM is an approach that offers a collaborative way of working throughout the entire lifecycle of an asset, underpinned by the creation, collation and exchange of information. The successful adoption of BIM is as much about cultural change as it is about the uptake of technological enablers.
Fundamental to the success of BIM is the creation of a Common Data Environment (CDE). A CDE provides a robust, structured and managed system to record and register health and safety information throughout the project lifecycle. Information contained within the CDE can be used by all involved parties throughout all phases of the building’s lifecycle: design, construction, commissioning and end-use. This enables users to identify, mitigate, manage and communicate risks throughout the project.

An example of the value of working within an established common data environment is illustrated in Case Study 1, which describes the Environment Agency’s work to maintain the Thames Estuary flood defences. Within the TE2100 project COBie (Construction Operations Building Information Exchange) is used to capture data about flood defence assets, including important health and safety information, and to ensure that this information remains current and available over the length of the project.
CASE STUDY 1

The Thames Estuary Asset Management 2100 (TEAM2100) project – The Environment Agency

The Thames Estuary 2100 project (TE2100), led by the Environment Agency, is a comprehensive action plan to manage flood risk for the Tidal Thames from Teddington in West London, through to Sheerness and Shoeburyness in Kent and Essex over the next 100 years. Flood risk on the Thames Estuary is increasing. Climate change is causing increases in sea level and river flows, and new development, such as the Olympic Park, Canary Wharf and the Thames Gateway Port, within the floodplain are increasing both the risk and consequences of tidal flooding.

TEAM2100 is the Environment Agency’s 10-year programme to refurbish and replace tidal flood defences in London and the Thames estuary, which include the Thames Barrier and 350 kilometres of flood walls and embankments, smaller barriers, pumping stations and flood gates. This system of defences protects 1.25 million people and £200 billion worth of property. TEAM2100 is the first phase in a 100 year strategy for the River Thames looking at the needs of the estuary as global factors such as climate change impact our lives over the coming decades.

For a project of this length and magnitude, it is crucial that information is shared for the duration of the project, and then continues to be available for future maintenance and renewal activity. This project is pioneering the use of a Common Data Environment to capture information about flood defence assets, to store health and safety information using a common COBie format, to ensure that this information is kept available and retrievable over the long term.

During infrastructure inspections, data are captured on iPads, uploaded to the GIS based information system, and made available for editing. The GIS format enables relevant asset information to be captured and linked. Using the COBie to structure hazard and risk information ensures a common standard of readability and ultimate retrieval. Key information can be reused many times if necessary. This means information will be available when it is needed in the future.
Planning phase

Building Information Modelling (BIM) and 3D visual medium can play an important role in reducing health and safety risk during design and through the project lifecycle. The use of BIM techniques enable the project team to visualise the project within the virtual environment at each stage of development, integrating each contributor’s work into the model and enhancing communication among the different project stakeholders, such as the design team, subcontractors, operators and others that contribute to the planning process of a project. In particular, use of BIM facilitates the early identification of site hazards enabling designers to eliminate or mitigate risks before physical work begins. Where it is not possible to remove hazards, workers can be prepared in advance, and appropriate controls introduced. Likewise, linking the digital model to a schedule adding the time dimension, and moving to 4D, allows the construction sequence to be rehearsed digitally and potential hazards identified.

Visualisation

The use of visual representations allow complex construction challenges to be more easily understood and communicated, clashes to be detected, and designs and processes to be tested and practiced in a safe environment.

When viewing 2D plans of buildings, health and safety professionals with knowledge and experience will be able to identify issues and potential risks. However, interpretation can be obstructed by the complexity of drawings. 3D models remove the requirement for users to visualise the design themselves, and provide a usable and unambiguous visualisation of the design. This enhances the process, as well as allowing those who are unfamiliar with building plans to understand and discuss the site.

BIM modelling can be particularly useful for older buildings; these can be particularly difficult to understand from plans, as they often consist of several structures and extensions. Underground structures can also be modelled, allowing them to be explored in a way that would not be possible otherwise. Use of 3D models also means that a building can be evaluated and discussed from a safe location; e.g. a roof can be assessed without the need for individuals to be at height.

Recent developments in surveying techniques are improving the capabilities of BIM visualisation. For example, drones can be used to capture an aerial view of a site, and this data can then converted to a 3D model. This can be faster and cheaper than other techniques, and also decreases risk by removing the requirement for surveyors to work in danger (e.g. at height, or near hazards). These techniques can also benefit projects by allowing the involved parties to gain an understanding of both the immediate and the surrounding site. An example of this is shown in Case Study 2.
CASE STUDY 2

The use of BIM as a platform for design evaluation and review

Building Information Modelling (BIM) and 3D visual medium can play an important role in reducing health and safety risk during design and through the project lifecycle. When reviewing typical orthographic drawings (2D elevation and sectional views) of a design, the complexity of the drawing can often hinder interpretation and the ability to visualise the design and identify potential risk. A 3D model provides an unambiguous view of the design and allows users to undertake a more subjective and focused assessment of the design in relation to its real world. Such modelling allows designers to have a greater understanding of the hazards within the context of the site, allowing hazards to be identified earlier, and ideally before building work has begun.

During a recent valve pit design review at Eakring, National Grid’s state-of-the-art training facility the 3D model was shown to a health and safety representative during a HAZID study who immediately pointed out that although hooped safety ladders and barriers were provided (Figure 4), a gated access point was necessary to further reduce safety risk (Figure 5). Using BIM and data rich models as a tool to support design review and process safety reviews, infringements can automatically identified by applying predefined rules based on component categorisation to identify area of potential risk and aid risk management early in the design process.
Testing and simulation of design solutions

BIM can be used to facilitate the testing and practicing of design solutions. This allows potential solutions to be modelled, assessed, and compared against alternative solutions in terms of their relative benefits and risks. Augmented or virtual reality techniques can be used to build a site in a ‘safe’ environment, where risks can be explored without the danger of harm to workers or resources. In this way, the site can be built twice; once in a virtual environment, where mistakes can be made and different designs explored, and once in the real world environment. Where 4D BIM is used, which incorporates time as a parameter, the risks present and the progress complete to date can be assessed for different stages of the project lifecycle.

Experience has shown that the benefits of BIM during the planning phase include:

- Design solutions can be configured and assessed without exposing workers to risk.
- The benefits, risks and costs of different solutions can be compared.
- Workers can gain a better understanding of the project and its requirements, and can plan future activities more effectively.
- 3D visualisation allow problems to be detected at an early stage in the project.
- Clashes can be eliminated or mitigated quickly, reducing risk on site.
- The model facilitates collaborative working, and speeds up the rate of decision-making.
- Workers are able to gain a greater understanding of the project and the intended sequence of works.
- Workers can provide input to improve the project plan and reduce risk.
- The viability of equipment, structures and infrastructure can be tested before being committed to.
- Construction or installation sequences can be modelled and assessed in terms of viability.
- Potential issues can be identified and steps taken to address or mitigate them.
- BIM objects can be used in planning health and safety and logistics on site.
CASE STUDY 3

Planning of the M5 Smart Motorway Upgrades - Balfour Beatty VINCI JV

A joint venture between Balfour Beatty and VINCI has been utilising the BIM methodology during smart motorway upgrades to a 10 mile section of the M5 Junctions 4a to 6 in Worcestershire. These upgrades aimed to increase capacity, reduce congestion and shorten journey times for the thousands of road users who use these parts of the network every day. Extra capacity will be added to the motorways through the conversion of the hard shoulder to a permanent running lane. Electronic signs, operated by a regional control centre, will be installed to manage the flow of traffic in response to driving conditions. Project challenges included time constraints and a small physical space in which different works needed to be carried out. BIM was used to co-ordinate all works and to produce an effective schedule that took into account the time and space limits. The project was due to begin in January 2016, which meant that the plan also had to consider potential adverse weather conditions.

The joint venture utilised 4D modelling for all critical activity which had the potential to impact project timescales to enhance understanding of the works sequence prior to starting on site, reduce waste and inefficiencies, avoid operational and logistics clashes and mitigate health and safety risk. The programme of works highlighted key interfaces between trades, gave a general overview of the complexity of the scheme to the team, and highlighted the short amount of time available in which to complete works. This was used to prevent clashes in work schedules, whereby some parts of the construction are preventing others from taking place (e.g. a team needing to wait for another team’s concrete to dry before starting their part of the work). This served to decrease risk to workers, as well as preventing the wastage of resources.

Part of this project involved the use of lifting equipment to remove existing MS3 gantries. A decision had to be made regarding whether to undertake this work under a 2 lane closure, or whether a full closure would be required. The benefits of a 2 lane closure are that the motorway is able to remain operational, and the impact on journey times is reduced. A 4D model was created that modelled the project’s lifting plans and other intended works. This 4D model sequence was then shown as part of a meeting. It became clear to members of the group that, during the planned works, the lifting equipment’s arm came into close proximity to the running traffic. This led to the team coming to the collaborative decision that the project required a full closure; a 2 lane closure would not be sufficient due to the risk that would be posed to members of the public. Use of the 4D model assisted collaborative working, and meant that the issue was identified early in the project.

Figure 5 4D Model of works sequence

https://www.youtube.com/watch?v=C8VDI0RXpBM&feature=youtu.be
All teams were consulted at an early stage, and were provided with the opportunity to input comments in order to improve the work plan and to minimise risk. Use of the 4D model enabled teams to devise an efficient solution to the risk of work zone clashes, which in turn enabled the project to be delivered on time and to cost. This enabled teams to gain a greater understanding of the project, to have confidence in the co-operative schedule that was created, and to trust that the targets of the work would be met.

Balfour Beatty VINCI's use of the BIM approach broadened its scope to include day to day project management taking the software beyond its standard operational practice. Using this innovative enabled Highways England to re-open a stretch of the M5 three and a half hours earlier than planned during a scheduled 12-hour closure, removing planned disruption for over 26,000 of road users on their morning commute. Information gathering during the project meant that the teams would be able to plan future projects that also minimised risk to workers, minimised wastage in terms of time and cost, and involved the efficient co-ordination of works. The 4D model could also be used in future as a rehearsal tool, to enable workers to learn and practise activities before undertaking them in the real environment.
CASE STUDY 4

Bond Street to Baker Street tunnel relining project – Transport for London

The section of the Jubilee Line between Baker Street and Green Park, constructed as the Fleet Line in the 1970’s has experienced a number of concerns with water, sand and acid ingress; and concrete spalling primarily as a result of tunnelling through Lambeth Group geology.

The Bond Street to Baker Street Tunnel Remediation Project, undertaken by London Underground achieved a world first. A 200 metre section of the concrete lined train tunnel was completely refurbished, whilst maintaining a full train service of up to 30 trains per hour, running at full operating speed. This addressed the most difficult concern, that of concrete spalling from the segmental tunnel. To eliminate the spalling and mitigate the risk to future operations the southbound tunnel was relined with Spherical Graphite Iron (SGI) Rings above the track. This was the first time that such a repair had been undertaken during engineering hours. About half the rebuilding was carried out at night in the standard 3.5 hour engineering hours period. The remainder was carried out in 52 hour and extended possessions. Significant commercial and construction risks needed to be managed.

Logistical planning was required, in terms of the transport of equipment, access and egress for people, and changing passenger hours. A Common Data Environment (CDE) was created that allowed everyone, including suppliers and manufacturers, to access project information. 3D laser scanning was used to capture existing aspects of the tunnels and identify any spooling or cracking within the tunnel lining. Modelling techniques were then used to explore available design and build options, to assess the potential risks associated with each option and to

https://www.youtube.com/watch?v=eN2MBIfhxBI
develop a project plan, incorporating links between assets and data. This approach served to reduce the number of site visits needed to assess the extent of remedial works and allowed everyone ‘access’ to the site without the need to physically visit. Using a 3D model meant that ideas could be planned, built, commissioned and tested virtually, it was possible to select and then test the safest methods in advance, e.g. the use SGI rings to partially replace the tunnel structures.

A key success of this project was the development of the custom built Segment Handling Plant (SHP; Harmill Systems), which utilises a robotic lifting arm, fixed to a mobile work unit, to fit the SGI rings in place. Use of the 3D model enabled technical problems to be dealt with prior to the work commencing and reduced the impact of the work on the public. Using the SHP it was possible to undertake a safe and efficient changeover process all within the limited track possession time afforded each night. Use of the VR model also allowed the training, testing, and upskilling of the operators.

Overall, the project was successfully completed without disruption to service, and without compromising the safety of the workforce or the public. The work was completed four months ahead of schedule, and slightly under budget the £34.4M budget. A 15% saving in planning, risk assessment, safety and assurance costs was realised. Primarily due to increased efficiency and a reduction in the hours spent in the tunnel, reducing the exposure (and therefore risk) to the workforce.

Figure 10 BIM model of the mobile work unit
**Construction phase**

In all phases of a project, the use of BIM models allow for the data to be extracted and manipulated. At the construction phase the BIM methodology allows the design team to construct a 3D model that represents the intended build specification. This virtual representation allows the contractors to interrogate the model and see how the intended systems (architectural, structural, mechanical, electrical, etc.) integrate, reduce conflicts and eliminate the need for costly changes. Identifying and fixing problems early means fewer health and safety hazards once physical construction begins.

**Constructability review**

Constructability reviews focus on detecting construction risks and hazards, and identifying ways in which to remove them. The use of 4D modelling as part of a constructability review assists designers in identifying risks, and encourages them to consider and communicate how they intend their design to be constructed safely. Using the model for this review facilitated the group in detecting potential problems, and removed the requirement for the group to read large quantities of paperwork before discussing the design together. The early identification of hazards and mitigation strategies meant that issues could be addressed before construction started.

BIM can also be used to check the viability of equipment and structures. Libraries of 3D object models, such as machinery, vehicles and constructions, are available to designers for inclusion in BIM models. Object information, such as weight and dimensions, is incorporated into these models. This information is embedded for the benefit of designers, but may also be of interest to other parties, such as health and safety professionals or those planning site logistics. For example, the size and weight of an item may impact its transportation on site, or an object may need to be treated differently if it is associated with a hazardous substance. It may not be clear who will need access to certain object information; as this information is embedded within models, it is available at a central point and can be accessed by all involved parties.

Where off-site construction is used, BIM can be used to ensure that the constructed parts can be manoeuvred into the correct position on site. A 3D site model can also be used to determine whether the intended site machinery can be accommodated; a model of the vehicle can be added, and the size of paths and turning circles can be assessed. Vehicle blind spots can also be buffered, to assess the safety associated with a particular vehicle. Models can also be used to plan how pedestrian and public access will be protected, and to check the suitability of the locations of welfare provisions and other site facilities.
CASE STUDY 5

Constructability review at National Grid

BIM was used as part of a constructability review at National Grid; a key aim of this process was to challenge the current approach of producing and working from large 2D drawings. A 4D model was created that showed the various stages of the building’s lifecycle. Various parties involved with the construction then met to assess and discuss the project. This was done for all phases of the project: site-preparation, excavation, civils, mechanical, testing and drying, commissioning, and reinstatement and demolition.

The introduction of time as a 4th dimension allows hazards to be assessed over time, and facilitates the assessment of sequences of works. Use of BIM for this project meant that the group were provided with a clear, unambiguous visualisation of the site and planned works within a safer environment. The simulation was sufficiently realistic, while also being removed from the true environment, to allow a focussed assessment to be made without distraction. This made it easier for potential problems to be detected, meaning that issues were identified early in the project. This prevented mistakes being made in the real environment. Use of the 4D model also assisted collaborative working, and enabled all members of the group to fully understand the proposed construction sequence, allowing decisions to be made quickly. The 4D model could also be used as a rehearsal tool, ensuring the work was carried out right first time. Overall, using BIM as part of the constructability review lead to a reduction in programme duration of 34 days, and associated cost savings (including labour and plant) of approximately £220,000 on a project costing £1.2 million.
Clash detection

The ability to view buildings and structures as 3D models, as opposed to 2D drawn plans, makes it easier for users to detect potential problems. Although health and safety professionals with training and experience will be able to detect hazards within 2D plans, 3D BIM visualisations enhance this process. For example, it is much easier for individuals to detect clashes between structures when they are provided with a clear, unambiguous visualisation of a site. This is particularly relevant with regards to MEP (Mechanical, Electrical and Plumbing) works where elements such as, power distribution, telecommunications, ventilation and air conditioning, water supply, and fire protection systems can all be incorporated into the design model and automatic clash detection features can be used to identify hard collisions. These can then be designed out or mitigated at this earlier stage, reducing the time and costs associated with remedial actions during the construction phase. Use of 3D visualisations also enables individuals who are less familiar with 2D plans to contribute to clash detection.

Off-site construction

Off-site construction has the benefits of allowing the transfer of risk to a safer environment, increasing efficiency and reliability, reducing waste, and improving relations with those living close to the site by reducing deliveries and the nuisance associated with building work. If BIM is utilised at the outset of a project and models are produced promptly, decisions can be made early in the project about how much construction takes place off-site.

BIM was used by Nomenca to facilitate off-site construction during a panel-replacement project. It was determined that the replacement of an existing panel with a new one would incur significant cost. However, a cost-saving solution was proposed whereby a new panel could be manufactured in-house and later transported to site for installation. A 4D BIM model was utilised during the project, which provided time and cost information and earned value analysis. Multiple elements were designed and manufactured at Nomenca’s Warrington facilities, which led to significantly reduced potential health and safety risks, a saving of £35.5k of CapEx, a programme saving of 5 months, a reduction in the carbon footprint of the project by more than 200t of CO₂, and improved relations with the community by removing the need for 24 HGV deliveries.
GlaxoSmithKline (GSK) used BIM to create a pharmaceuticals facility with Bryden Wood’s ‘Factory in a Box’ concept. This concept involved all parts being pre-fabricated off-site, packed into shipping containers in the reverse order to which they would be required, and delivered to site in a shipping container. This allowed all parts of the construction process, aside from final assembly, to be removed from the site. Construction plans were provided, which were based on groups of components. These component groups were standardised and recorded on a database alongside information about their characteristics. All systems and components were catalogued in this way, and were tagged with bar codes to enable each part to be tracked at each stage of the process – from manufacture right through to distribution and construction. This enabled GSK to precisely track the time taken to manufacture, load and deliver the parts, which provided accurate data in terms of the cost and labour requirements. This allowed GSK to devise an estimate of the cost of constructing an entirely new, bespoke facility, which could be remodelled to change its layout or capacity, within a matter of days.

Benefits of BIM: Off-site construction:

- Risk can be transferred to a safer environment.
- On-site activities are reduced and simplified.
- Cost and time savings can be made.
- Using tracking, the cost and labour requirements associated with parts can be accurately calculated.
- Using the BIM model, an estimate of the cost of constructing a new building (including a building with a different layout or capacity) can be calculated rapidly.
CASE STUDY 6

Uttlesford Bridge Water Treatment Works Combined UV and Hypochlorite Dosing

General Scope Background

Uttlesford Bridge is a small borehole pumping station, complete with hypochlorite dosing and a contact tank. This is then boosted to 9 bar into supply and to remote reservoir. The plant is dated and is causing nuisance maintenance issues. Therefore it was decided to replace the dated equipment with a new, more efficient 14Mld system. The existing site was 3D laser scanned over the course of a day to capture existing asset layout and data. The new water treatment ‘Off site build’ solution is shown in red on the 3D laser scan in Figure 13.

A Ground Penetrating Radar survey was also conducted to accurately model the underground services and this was mapped into the 3D model to clearly show the interface with new buried services.

Figure 13 3D laser scan of existing asset layout and data

Utilising Nomenca’s library of parts and Common Data Environment a fully immersive virtual environment was produced within 2 weeks. This was used as a basis for the presentation of the proposed solution and its interface with existing assets.

Figure 14 Virtual environment showing the proposed solution
Nomenca took the decision to design and build an off-site solution. The £1.7m project was delivered using SAFE (Skilled Assembly Factory Environment) production methodology with the assembly taking place in Nomenca’s Warrington manufacturing facility. This approach means that products are produced off-site in a safe environment resulting in a reduced programme of works, improved health and wellbeing, guaranteed quality and a reduction in raw material wastage. The use of the SAFE initiative serves to mitigate health and safety risks, by moving traditional construction activities from site into a controlled production / manufacturing environment.

Significantly, the use of a BIM approach enabled a design to be produced with no requirement for a civil base; everything was self-contained on a structurally integral base and utilised ‘plug and play’ technology.

**The Combined UV and Hypochlorite Skid**

Due to limited shut downs available to site, and program constraints on site works in commissioning any new equipment was deemed a high risk activity. Therefore an offsite build of the disinfection equipment was very attractive to the client, and not to mentioned the reduced health and safety issues of building on site, but also reduced construction restrictions and noise to local residents.

The skid is 20m long, 4.2m wide and 3.4m tall, with a SR4 rated kiosk top hat section and weighs 20 tonnes. It houses a new MCC, which will be the main site MCC and powers not only equipment situated within the new skid, but the new borehole pumps and existing surge vessel. The raw water from the boreholes is pumped at mains supply pressure through the new UV reactors and hypochlorite dosing system. A new additional booster pump to an auxiliary reservoir in case of a network shortage is also housed within the new skid. All equipment is installed, electrically connected and process tested prior to delivery to site.

The design team used a Federated BIM 5D model, incorporating a construction phase time-line model and detailed cost capture/reporting enabling earned value analysis. Being a federated model the supply chain and Nomenca design team were able to collaborate in real time within the same model. The model was also linked to procurement schedules so that any changes in real time were immediately reflected. Component purchasing was generated from the model linked to suppliers SAP systems, enabling production slots to be reserved to meet the assembly programme, thus reducing assembly timescales.

The model was also used to immerse Nomenca production and assembly personnel into a virtual environment providing them with advanced training on equipment assembly and mounting; this negated the traditional learning curve.

As part of the factory test and inspection process a 3D laser scan was conducted of the finished package plant and integrated with a scan of the key mechanical interfaces at site to ensure a right first time fit.
Benefits delivered

From initial survey to a fully commissioned water treatment plant took 16 weeks, with 8 weeks of this being the factory assembly. The SAFE approach significantly reduced health and safety risks, such as:

- 34,000 man hours removed from site construction
- Elimination of more than 30 heavy vehicle movements
- Virtual Engineering environment to train factory assembly teams
- Reduced manual handling on site
- Lifting eyes base mounted to negate the need to work at height
- 3D Model and scan shared with Crane Company allowing all lifts to take place from one crane position

In addition the following benefits were also realised:

- >32% CapEx saving (£800k)
- 5 month programme saving
- Carbon footprint reduction of more than 200t CO2, and
- Improved relations with the local community by reducing vehicle movements.

Figure 16 The complete unit being lifted into place without the need to work at height
CASE STUDY 7

Construction of a pharmaceutical facility – GlaxoSmithKline

GlaxoSmithKline (GSK) is one of the world’s largest pharmaceutical companies. As part of GSK’s corporate responsibility strategy the Developing Countries and Market Access (DCMA) business unit is dedicated to increasing patient access to GSK medicines while expanding the company’s presence and helping it to build a sustainable business in developing countries, which often requires construction activities in difficult, varied and underdeveloped markets.

Bryden Wood’s Design for Manufacture and Assembly (DFMA) solution enables rapid deployment of pharmaceutical facilities in emerging markets. The ‘Factory in a Box’ concept utilises a DIY, flat-pack approach. Rapid, safe site construction is delivered through composite DFMA ‘components’ that can be delivered from Europe in shipping containers, having been packed in the reverse order needed for the re-assembly process, and constructed on site. The use of colour-coded components, coordinated through the BIM model, reduced the skills required by workers to complete the step by step assembly process. This process also meant that only a small number of unskilled workers were required on-site and served to increase the speed at which the facility could be constructed. Less people, fewer site materials and operations and more formalised process with improved instructions produced a simplified site environment, leading to significant site safety improvements. The design of the facility’s construction also reduced the need for potentially dangerous working practices such as working at height, with all roofing assembled at ground level and lifted into place with hydraulics or chain blocks.

The 4D, fabrication quality, model allowed virtual build exercises to be used to optimise the assembly sequence, test health and safety aspects and create visual method statements accessed via QR code. A range of digital tools, such as model-based tool box talks, were leveraged to allow the delivery of a sophisticated construction system, by a low-skilled workforce. Pre designed 3D components containing full cost / construction information drag and drop from the component library in premade configurations following ‘snap in place’ assembly rules and live link to the associated library of construction and fabrication details. The intention was that the completed building would be a precise replica of the original digital model, with each component being a physical representation of the digital schematic (including all related...
BIM data). This method allowed GSK to devise an estimate of the cost of constructing an entirely new, bespoke facility, which could be remodelled to change its layout or capacity, within a matter of days. Such flexibility in terms of rapid design adds further value to the process. Similarly, ongoing life cycle management is incorporated as standard via QR code asset tracking linking all components to their design and operations and maintenance information, as well as the installation and cost metrics and service history.

Proof of concept was demonstrated when eight ex-Gurkhas, unskilled in construction, were able to reassemble a prototype building, demonstrating the quality of the facility while meeting GSK’s high compliance standards. Although the finished product is estimated to cost 15% more than a standard local building, the factory in a box is built to world class quality and safety standards not always achievable using the local supply chain. During the build process an estimated saving of 30% over the same facility built conventionally was realised. The use of off-site design and pre-fabrication allowed on-site labour requirements to be reduced by 75%, and saved 60% of build time cutting the construction programme from 12 weeks to 4. After completion, GSK calculated that the workers spent 82% of their time on-site productively, compared to the typical figure of 60%.

**Figure 19** Colour coded components coordinated through the BIM model reduce skills required

**Figure 20** (accessed via the QR codes) was captured throughout every stage of the process from fabrication, logistics and delivery to installation and operation.
Demonstrating construction requirements on site

The models created during the design and planning phase of the project can be used to visualise critical phases of construction or key steps in the build process, providing an onsite demonstration of the residual risks present during these tasks. The locations of hazards, such as asbestos or confined spaces, can be identified and highlighted within the models and presented to workers at the ‘sharp end’. As such, workers can be made aware of hazards in real time, including those that may arise as a result of other activities occurring close to them. Visualisations can take the form of instructional sequence videos, or simulations involving virtual or augmented reality and can enable workers to gain a greater understanding of the tasks that are required of them, and an understanding of the controls in place to reduce risk.

BIM was used in this way throughout the renovation of London Victoria Station (see Case Study 8). The project involved the construction of a number of underground tunnels. Due to the process and the position of these tunnels, the project posed risks to ground stability and existing infrastructure. Through collaboration between the design and contracting teams, and use of a common data environment, a multi-disciplinary model was constructed based on as-built data collected during the jet grouting and a ‘gap model’ was produced prior to each stage of tunnelling that identified ‘gaps’ and classified them with regard to their risks to health and safety. This approach allowed remedial actions or safe methods to excavate through the ‘gaps’ to be agreed in advance by the team members ahead of the tunnelling operation.

Figure 21 Onsite collection of data
CASE STUDY 8

London Victoria Station upgrade project – Transport for London

The Victoria Station Upgrade (VSU) project was a £700 million capital programme of work undertaken by London Underground Ltd to reduce delays, improve congestion, provide step-free access and quicker journeys in and out of the station. The new tunnels are constructed at shallow depth in a mix of water bearing gravels and London Clay, the former of which required treatment by jet grouting to stabilise the ground and limit ground water ingress for tunnelling.

A Taylor Woodrow / BAM Nuttall (TWBN) JV was awarded a Design and Build contract for the works in 2010. Mott MacDonald as the Lead Designer developed the utilisation of BIM for placing the project’s 2400 jet grout columns around existing utilities and live tube tunnels. By using this approach, Keller, acting as specialist jet grouting sub-contractor, were able to identify unavoidable ‘gaps’ of untreated ground in the jet grout block that occurred due to lack of drilling access.

If not identified and treated, these ‘gaps’ would have resulted in ground instability, water-inflow and potential tunnel collapse. Particularly in a dense urban environment such as Victoria, the consequence of such an event poses unacceptable risks; including to the immediate safety of the contractor’s personnel; damage to high value utilities and heritage listed infrastructure; safe operation of the London Underground railway, and; safety of the general public using the traffic carriageway above the tunnel alignment.

BIM was used to manage this risk throughout the tunnelling operations. To facilitate safe construction, the TWBN team used BIM to produce a design that resulted in optimal coverage of jet grout around the new tunnels whilst ensuring the risks to the existing infrastructure were minimised. A risk-register was produced prior to each stage of tunnelling that classified ‘gaps’
with regard to their risks to health and safety. This approach allowed remedial actions or safe methods to excavate through the ‘gaps’ to be agreed in advance by the team members ahead of the tunnelling operation.

During tunnel construction, the multi-disciplinary BIM model was used on a daily basis at Required Excavation and Support meetings to predict ‘gaps’ during tunnel advance and allow any necessary agreed investigative and remedial works to be undertaken from a safe and stable tunnel face in advance of further excavation.

**Figure 24** BIM model to design optimal coverage of jet grout whilst protecting existing infrastructure

**Figure 25** Concept of producing Construction sequence model for PAL tunnels
Risk communication

The BIM model is a useful tool in visualising solutions to complex and challenging construction problems and communicating those solutions to the front line workforce. For example, Costain use BIM and GIS to identify key risks when working on a live railway include safe access to the track, how to get trackside safely, ensure that the workforce are working in the correct location and to provide awareness of overhead cables and other utilities. 360-degree photographs are generated to visually represent access areas and provide advance familiarity with the working environment. Users are able to access these on mobile devices prior to arriving on-site at the start of shift. These photographs are supplemented with laser scans to capture a realistic 3D representation of access points to provide better understanding of the access requirements and communicate more effectively. This information is optimised, referenced geospatially and made available on tablet devices through mobile GIS. The point clouds generated from these scans can be measured and used for both interface / reference design and logistics planning – providing certainty that specified plant and equipment will fit and that access / egress requirements will be met.

This information is supplemented with data relevant to the area being worked on, colour-coded and annotated accordingly to illustrate the direction of travel of trains (when not working under possession) and other hazards. This is particularly applicable for night-working when photography will not present a realistic representation of reality. The system is updated as work progresses to ensure that operatives undertaking successive work are always provided with the latest, up to date information. Laser scans will also be updated at regular intervals to ensure that they reflect changes as the project progresses.

BIM is used to communicate hazards and safe working practices by illustrating risks and safety procedures visually. ‘Hazard Triangles’ are associated to components in the 3D model. These are linked to the live risk register and colour-coded accordingly (RAG scoring for high / medium / low risks). As risk is closed out or the likelihood / impact mitigated the colour of the risk is downgraded, providing a live illustration of the risk register for simple communication. These

**Figure 26** Laser scan outputs Bridge

**Figure 27** Laser scan point cloud, London
triangles are also recreated automatically on associated documentation, including screenshots and 2D drawings, and incorporated into 4D sequences — linking the model to the programme, illustrating risks at particular points in time. These risks are annotated with Risk IDs and Risk Descriptions.

A 4D model of the site was created, and hazards were marked on the model with warning triangles. Denoting hazards with warning triangles allowed users of the model to quickly identify risks. Hazards were also accompanied by hyperlinks, which linked to the risk register. This allowed users immediate access to additional information about each hazard, and removed the need for other information to be searched through. Some hazards were also accompanied by a photograph of the risk, which allowed users to visualise the area. Links to information such as mitigation procedures and controls to site access were also included in some instances. Embedding these links within the model meant that all information could be accessed from a central point by all parties involved.

Using the contract-wide Geographical Information System (GIS) the information about hazards according to their location is captured and plotted on a map. This allows all related information to be retrieved by location enabling a user to select an area and view photographs, documents and links to models and provides a simple user interface that is familiar and intuitive. This system can also be used to store information about movement of materials and associated CoSHH data.

Visual method statements are created for start of shift briefings and incorporate Health & Safety information — showing walkways, locations of first aid kits, fire-fighting equipment, sources of ignition, etc. Walkthroughs of models will be captured as video and displayed in welfare areas. As part of the C336 contract for Crossrail, Costain have implemented a private YouTube channel, which allows their operatives to login and securely view annotated site videos. All registered users are able to mark-up any hazards, best practice, or other observations so that the information is captured within the video. Each successive viewing shows the marked-up information, including who has added to the video and when.

**Benefits of BIM: Risk communication**

- Highlighting hazards on the model allows users to quickly identify risks.
- Sequences that might be difficult to visualise via text can be quickly conveyed via a 3D model.
- 3D modelling enables workers to gain a greater understanding of site and project risks.
- Models can include links to additional information and images, which enables users to better understand particular risks.
- Embedding links within the model means that all information can be accessed via this central point by all parties involved.
CASE STUDY 9

M25 DBFO widening initial upgrade sections – Skanska / Balfour Beatty JV

The Skanska Balfour Beatty Joint Venture and Atkins implementation of BIM on the initial upgrade sections of the M25 helped to achieve a design and construction rate which was twice as fast as previous comparable projects. This meant delivering £1 million of works per day to complete 1.6 km of highway per month, while maintaining three lanes of traffic in each direction during the working day.

To do this, all existing infrastructure was modelled in 3D, to an appropriate level of detail, to allow each discipline to develop their design. The 3D models from each design discipline were then brought together in AutoDesk Navisworks and the automatic clash detection function was used to identify both physical conflicts and infringements of clearance zones.

This allowed for the designs to be adapted before any work had begun – reducing abortive works and producing a design solution suitable for all disciplines. Following on from the collaborative development of the design, the BIM models were issued to site for the construction phase, with 120 members of staff receiving training on their use. The models, presented via iPad, were then used by the site teams for daily briefings, assessing the impact of design changes, temporary works management, traffic management and for briefing Network Rail prior to a possession of the East Coast Main Line. The visualisation capability of BIM was fundamental to understanding the safety risks and demonstrating safe construction methods on long, linear highway projects.

Figure 31 3D model of the M25 upgrade
Beyond the construction site

Visualisations of construction tasks and other activities, in the form of instructional sequence videos or simulations involving virtual or augmented reality, can also be used to allow workers to learn and practice required tasks or sequences. This allows tasks to be undertaken within a simulated environment, to reduce risk when they perform the task in the real environment. This is particularly valuable for tasks that are complex, high-risk or not undertaken frequently.

BIM is used by National Grid at their Eakring training centre to plan maintenance procedures and construction projects. Virtual reality training material and user manuals are embedded within 3D models, to allow activities to be planned, learned and practiced in a safe environment. Models can also be used to assess workers’ performance during these simulations; mistakes can be assessed, and error-reduction methods can be developed and tested via the model. Use of these methods allows the user to experience the environment as if they are actually on site, and to gain an accurate impression of any visibility or space restrictions that will be present. The use of BIM can also enable workers to gain a greater understanding of the demands and risks associated with particular tasks and environments.

BIM models can be used for virtual prototyping of complex structures and assemblies prior to any construction or material procurement, providing asset integrity validation with no commercial or health and safety risk. Virtual prototyping can be used to validate a design by simulating operation...
and process conditions in the real world to identify potential issues with regard to structural integrity, construction and maintenance.

This also provides the ability to simulate different methods of construction to identify, remove and reduce on site hazards which can be integrated into the construction plan, method statements and risk assessments prior to commencing on site works.

**4D time linked construction assessment undertaken by National Grid**

BIM models and virtual reality provide a mechanism for site modifications, for example the installation of new equipment into an existing site to be assessed, reducing the risk of physical clash and assessing spatial and construction requirements. Having the ability to identify potential construction or operational risks in an immersive virtual environment is a powerful risk reduction tool. Collaborative assessment can be undertaken using immersive VR and a time linked construction model (4D), allowing users to view the environment as if they were standing in the site to gain a realistic view and appreciation of spatial restrictions and visibility of other activities from a particular viewpoint. This can be used to assess construction access, traffic movement, visibility and coordination of construction activities which can be used to identify critical path activities and manage risk.

**Benefits of BIM: Beyond the construction site**

- Tasks that are complex, high-risk or not undertaken frequently can be learned and practiced in a safe environment.
- Workers can gain a realistic impression of the site, complete with any visibility of space restrictions.
- Workers can gain a greater understanding of the risks and demands associated with particular tasks.
CASE STUDY 10

Using Virtual Reality for Learning and development – National Grid

Visualisation using BIM models and virtual reality has been put to good use at National Grid’s Eakring training centre with real world benefit. Previously, National Grid’s trainees were trained on a range of electricity switchgear and gas equipment. However, the diverse range of gas and electricity equipment found throughout National Grid’s networks meant it was impossible for trainees to experience the full range of models in a training centre environment. VR provides a safe, all weather, solution for the delivery of operation and maintenance training to inexperienced operatives in a fault tolerant environment. The simulation of new operational procedures and method statements in a controlled environment, where errors can be corrected and procedures improved, allows for health and safety risks to be documented, procedures to be proven and risks suitably managed prior to undertaking the activities in the real world.

Virtual Reality has allowed National Grid to develop, simulate and improve procedures for higher risk activities such as in-line inspection of pipelines (i.e. pigging). The use of VR allows training to be both practical and theoretical; trainees are able to virtually strip down, put back together and operate the pigging equipment in a completely safe environment. VR is used to instil best practice behaviours and minimise on site risk by increasing the level of competency of personnel undertaking physical real world activities, prior to exposure to the inherent risks of an operational site.

National Grid also intend to expand the use of Virtual Reality tools with the implementation of fully immersive headsets (Oculus Rift) and remotely connected systems to allow multiple users (for design review and training) to interact with the virtual environment and other users in the scene from remote locations, all viewed from a 1st person perspective. The users can view the environment as if they were standing in the site to gain a realistic view and appreciation of spatial restrictions and visibility from a specific view point. This can be used to assess egress routes, visibility of signage and coordination of maintenance activities.

![Figure 33 In line inspection - Pig trap](image)

![Figure 34 Simulated Pigging Operation](image)
Mobile virtual reality modelling is also being used to reduce on site risk associated with asset impact and provide operatives and construction personnel detailed and pertinent information about buried assets. Mobile VR is the integration of the physical environment with a virtual model, representative of an existing or proposed asset. Augmented Reality in conjunction with BIM models can provide visual feedback of the location and physical attributes of a buried non-visible asset prior to any on site excavation or proposed modification being undertaken.

Figure 35 Use of VR for training purposes
Augmented reality

BIM can also be used in conjunction with augmented reality. This enhances visualisation of a site, by superimposing virtual models on the proposed environment in real time. For example, a smartphone or tablet showing a 3D model of a completed structure can be held up when on site, to allow designers or construction workers to gain a better understanding of what the completed site will look like.

This can facilitate users to make design decisions, or to detect potential issues. A virtual model can also be overlaid on a photograph of the site, such as Google Maps. For example, this technique could be used to enable users to visualise a street with underground pipes. These composite models allow the site to be viewed from different perspectives, allow risks and hazards to be evaluated, and allow designs to be validated prior to work beginning.

Augmented reality (AR) provides another means of leveraging BIM as the primary source of information on the project site. AR enables the co-location of digital and physical data in a single medium. Using hand-held projectors or ruggedized field tablets with special software to assist in tracking and registration, AR now enables the overlay of detailed, 3D BIM information onto the physical project site in real time and at full scale.

Benefits of BIM: Virtual and augmented reality

- Users can see what completed sites will look like, and visualise how individual components will fit with the existing aspects of a site.
- 4D BIM can be used to show how the site will look at different points in the project schedule.
- Use of BIM and augmented reality facilitates the detection and mitigation of risks and hazards.

Operational Phase

The drive to reduce the cost of built assets is beginning to promote the use of BIM technology in the operational phase of the building lifecycle. Building maintenance and operations account for approximately 90% of the total lifecycle costs. As part of the building commissioning process the design and construction project team generally deliver a structured information package to facilitate the management of the built asset. Within the BIM methodology, this includes the provision of an as-built model for handoff to the facility owners and operators.
This model serves as a central database and can be used as a digital asset throughout the operational phase of the building lifecycle including decommissioning and / or repurposing. Containing information and data about all the spaces and elements that form part of the building, the as-built BIM model facilitates efficient management, control and maintenance of the physical asset. It can be used to track, update, and maintain facilities management information to support better planning, operations, and maintenance decision-making throughout a building’s lifecycle. Each material, component and facility can be linked to the appropriate element maintenance schedules, properties, manufacturers and other relevant information within the model, which means that once a part of the building requires maintenance, detailed information can be identified efficiently from the as-built model.

The information contained within the as-built model can be used to plan and conduct future works after a construction is completed. This enables hazards to be considered, reducing the risk to workers and members of the public. Using BIM to embed this information into other systems can open up new and easier ways of accessing and using this information. For example, BIM was used to incorporate information from a health and safety file into Transport for London’s (TFL’s) construction design and management (CDM) data store. This was as part of a project to strengthen and refurbish the Hammersmith Flyover. The health and safety file consisted of predetermined sections of road, buildings, bridges, tunnels, signal junctions, cameras, bus stops and other structures.

An interactive map was created, which mapped these structures and denoted them with images of hard hats. Via a search function, structure types could be selected to appear on the interactive map. The structures contained all of the project health and safety information; selecting a structure brought up a link to the health and safety file, which contained this additional information. Use of this system assisted TFL in improving the management and sharing of information, and meeting their legislative duties. As health and safety file information could be accessed by all parties from one central location, potential hazards within a particular area could be quickly identified. Information was presented in a usable format, and users did not need to sift through information, making access quicker and easier, improving the extent of collaborative working, and the ease with which projects could be coordinated.
CASE STUDY 11

Hammersmith Flyover – Phase 2 refurbishment and strengthening (HFO2)

Prolonging the life of the iconic Hammersmith Flyover, which had been deteriorating due to significant corrosion, is of critical importance to TfL. With 70,000 users every day on a key strategic route into London, the structure presents many technical, logistical, programme and political challenges. The Hammersmith Flyover carries the four-lane A4 arterial road over the Hammersmith gyratory and links the west to central London. Constructed more than 50 years ago, the 622-meter-long pre-cast, post-tensioned bridge was in need of significant strengthening and repair. With little space for the installation of a new post-tensioning system, and the requirement to keep the bridge open to traffic during construction, the design team sought a way to accurately account for the details of the existing structure, and to precisely design a solution. Developed from a combination of drawings and advanced laser scanning, the 3D model helped inform, verify and challenge design assumptions, test construction scenarios and understand the many interdependent elements at work. This led to targeted physical surveys and identification of key risk areas.

While the as-built model and concept designs were being progressed, the team undertook internal and external laser scan surveys. The greater accuracy of both the scan data and subsequent changes to the as built model helped to inform the designed solution and construction tolerance required for the system. The laser scan also allowed the team to identify and model existing elements that were not included on the record drawings giving greater confidence of clash.
avoidance. Costain, appointed as Principal Contractor and Ramboll / Parsons Brinkerhoff as their designer, used the 3D model to refine the proposed design to incorporate their system preferences and construction methodology, driving design efficiencies, eliminating programme

and safety risks and speeding up repairs to minimise disruption to the public. This included an initial check of geometrical constraints using BIM, before a full size mock-up of a bearing pit and a pier, with timber replicas of the proposed bearings was constructed to trial the proposed solution. Costain, appointed as Principal Contractor, used the 3D model to refine the proposed design to incorporate their system preferences and construction methodology, driving design efficiencies, eliminating programme and safety risks and speeding up repairs to minimise disruption to the public. This included an initial check of geometrical constraints using BIM, before a full size mock-up of a bearing pit and a pier, with timber replicas of the proposed bearings was constructed to trial the proposed solution.

During detailed design Costain appointed a specialist post tensioning sub-contractor, Freyssinet, which brought about further design refinement. Opting for external precast and internal in-situ anchors rendered in Ultra High Performance Fibre Reinforced Concrete, which were to be bolted together through the existing structure, the purpose of the model changed from developing the design to proving fit of the designed elements. It is believed that this was the first time a full new prestress post-tensioning system has been retro-fitted to a bridge where it was not possible to remove the original. This unique project challenged the application of design codes and has the potential to change the way similar concrete structures are refurbished.

Successful application of this method required a highly collaborative cyclic process was established between all stakeholders throughout the project lifecycle, which involved modelling the proposed strengthening anchors and post tensioning cables, checking the design for fit and reporting, discussing and resolving issues; repeating the process until the design worked. By continuously checking for interferences throughout the design process, the team was able to address clashes between cable runs and against existing concrete to find a best-fit solution before construction.
How BIM might be used on smaller projects

Evidence suggests that the implementation rate of BIM in smaller construction projects (a value range of up to £5M) is notably lower in comparison to larger ones. One of the main reasons for resisting implementation is the perceived notion that lower value projects are not suitable for the use of BIM and while it is true that what works on large scale infrastructure projects may not work on small and medium sized projects, such projects can still benefit from implementing the BIM methodology.

Adoption of some of the BIM principles can enable small construction projects to access the inherent advantages and efficiencies available to large scale construction projects; many benefits of BIM are scalable, downwards as well as upwards. Within the experienced community of BIM users, it is evident that BIM has been and can successfully be used on projects of any value, providing that the methodology is managed correctly. One of the biggest advantages of using BIM was the significant improvement of visualisations, which benefited the design team, client and contractors.

The use of reality-capture technologies like 3D laser scanning and the use of aerial drone photogrammetry has enabled full utilisation of site-specific data during the design process. Such reality-captured site geometry supports the digital interrogation; designs can be visually represented from any viewpoint with the model. This provides clients, planners and members of the public with a much better understanding of the proposal in question often leading to successful planning outcomes.
CASE STUDY 12

Using BIM Technology to help plan Small Projects - InForm Architecture Ltd. / Charter Projects Ltd.

A small architectural design and build practice is using BIM, and its associated innovative technologies, to enhance the planning and delivery of a small project in the Brecon Beacons, Wales, where a 110 year old primary school is being converted into 3 residential units over 2 phases.

The initial investigation included a drone survey (high resolution 2D photography) of the roof scape to help understand the design and establish conditions such as weatherproofing, chimney location etc., while the images were later used for planning applications and publicity. This eliminated the need for anybody to access the roof, which was in poor condition. This technique did not allow precise measurement, but it did accurately capture the conditions of the roof and chimneys, and identified areas of asbestos cement roofing tiles as well as areas where tiles and lead flashing were missing.

A point cloud survey was carried out which captured both internal and external features. The nature of the traditional construction and age of the building meant that this survey helped reduce risks, eliminating the need for high level access around the roof trusses and crawl spaces. The scan had an accuracy of within +/- 1 mm and a range of 350m, which was quicker, safer, more accurate and captured more detail than a manual equivalent. Using an interactive model has avoided repeated visits to the site. The survey enabled better measurement of features such as internal walls, which in stone walls can vary significantly both horizontally and vertically. In one case the same wall varied by 200mm in depth across the length of the building. Further advantages came when the model was integrated into our workflow and formed the basis of BIM model. The model has been used repeatedly to check different dimensions, especially features such as the queen post trusses in the roof. The point cloud survey is now part of our mandatory workflow.

The BIM model was used to determine the best location for the proposed underground LPG tanks, enabling safety zones and clearance distances to be precisely designed at an early stage. The model has been marked up with skip locations and turning circles of the delivery vehicles while fire escape routes and welfare provisions have been integrated into the design process too. The model has also been used to plan the movement of construction materials, and to avoid the need for materials to be stored in corridors and becoming a trip hazard. For each trade and for each room in the project a specific drawing and schedule of quantities has been produced, along with carefully sequenced deliveries and works.
The model has enabled the specific design of services such as the electrical distribution box, to be fabricated offsite and positioned in the optimum place to serve all three dwellings. This included RCD fittings, and a schedule created to record the proper testing of the earthing arrangements. All this information can be recorded in the model.

The existing building has been extended and altered over the years using a variety of techniques, some of which are now outdated or not meet current standards. The structure is quite complicated and the roof truss joints are of a traditional construction which adds complications in meeting today’s standards. The model has greatly enhanced communication, not just in house but with consultants, because discussions can take place using the model and avoiding access to awkward areas which are often at height and poorly lit.

The window and trusses are a key feature of the renovation and conversion. Due to the quantity, the sheer size, the interaction with the first floor structure, and the irregular spacing these were carefully modelled. This enabled complete faith in the model and subsequent design along with the accurate sizing and updating of opening sizes as the project progressed. Any variations were captured efficiently by the model and automatically updated in the schedule.

Visualisation has proved very valuable and has helping to identify hazards at an early stage but also been used to clearly mark and to record why suitable mitigation strategies have been put in place. From the BIM model a 3D pdf document of the design model was produced and used to explain, using a smart phone, the design alterations to Building Control as well as other trades such as the window supplier. The use of the interactive model helped BC understand the implications of the roof and ceiling alterations.

Of specific concern to the BC officer were the two separating walls. Each of the junctions between the flanking walls and the queen post trusses were modelled and included the relevant fire stopping and acoustic provisions. In addition, the requirements for metal studwork and plasterboard were modelled to a high level of detail, with sizes of boards and studwork kept to a size manageable by one person. The aim was to facilitate as much offsite construction as possible, in this case the preparation of all the materials needed for each wall.

In summary, the use of BIM and innovative technologies has allowed InForm Architecture and Charter Projects to produce an otherwise complex scheme quickly and more accurately than producing the same scheme using more traditional workflows. The use of such a tool has allowed the clear documentation of the different construction phases to be accompanied by accurate quantities. It has allowed the identification and documentation of risks and has providing a single point of reference for all relevant documentation.

Level 2 BIM advocates communication and they have used this approach at a smaller scale to provide tailored documentation and visualisations to the right trades at the right time, enabling a smoother and de-risked process which allows them to focus on the design.
THE FUTURE OF BIM

Government Construction Strategy: 2016-2020 from the Infrastructure and Projects Authority sets out more details on how delivery, efficiency and performance across economic and social infrastructure projects might be achieved. It states that…

“The government will develop the next digital standard for the construction sector – Building Information Modelling 3 – to save owners of built assets billions of pounds a year in unnecessary costs, and maintain the UK’s global leadership in digital construction.”

The Government in conjunction with industry will develop the next generation of digital standards to enable BIM Level 3 adoption under the remit of the Digital Built Britain Strategy.

The successful implementation of BIM methods and processes can deliver benefits in producing efficient, coordinated designs, allowing clear presentation of complex and challenging construction information to a variety of audiences, while reducing safety risks through inherently safer design and practice. The digitisation of information through BIM enables more cohesive collaboration between designers, engineers and construction workers. With all data and documentation available from a central electronic location, all parties are able to access and discuss the same information. This improves project co-ordination and facilitates early collaboration.

Use of a common data environment (CDE) enables proactive risk management, recognises design risk management as an integral part of the design process, and allows the principles of risk prevention to be implemented in the development of the design solution. This provides users with the early opportunity to identify hazards, mitigate risks, and share health and safety information. Opportunities for BIM-related health and safety applications will exist at all stages of a project’s life cycle. They can be realised in a number of ways, including through communication, planning and risk management. During the design of BIM models, it is important that account is taken of safety considerations, and of how the model will be used throughout the project.

Using BIM from the beginning of a project allows health and safety risks to be identified early, and mitigation or elimination strategies to be implemented before physical work begins. Modelling and planning needs to take account of potential risk exposures which may cause ill health, for example by planning to eliminate the number of times concrete has to be cut on site, and therefore reducing exposure to silica dust. BIM can also be used to assess and compare work plans and to learn and practise tasks. These activities take place within the virtual environment, where mistakes and changes can be made without health and safety consequence. As well as improving health and safety conditions, the use of BIM can have commercial benefits such as reducing cost (e.g. through reduced waste, requests for information, and improved quantity take-offs), cutting programme time, and increasing the efficiency of project delivery.

The immediate challenge for industry in taking BIM forward is how to ensure the continued uptake of the BIM methodology to level 3 and beyond and by those outside of the early adopters. Although BIM is a way of working underpinned by digital technologies, its fundamental strength lies in the ability of
collaborative working to unlock more efficient methods of designing, creating and maintaining assets; to this end it is important that those at the front line are brought along with the pace of change. In the short term, this means that the construction industry needs to better understand the benefits that can accrue from an effective project common data environment, and how to collaborate to achieve these benefits. It is predicted that a lot of the savings associated with BIM will come in the occupier management and facilities management phases and feedback is needed to highlight the range of benefits that are being realised by implementing BIM across the information delivery cycle and allowing these to be fed back into future design. In the longer term it is important to recognise that technology is maturing and techniques are improving all the time; and it is anticipated that future work will achieve benefits beyond the ones presented here. Efforts should be made to identify and use those technologies that are most effective, particularly for smaller projects, in capturing and communicating risk information from the clients brief, through design to construction and on to the end user. As construction planning using BIM matures, the precision of planning should mean that hazardous substances, processes and environments are increasingly controlled through early design decisions.