

# Crossrail: A Case Study in BIM

Authors: Ilka May, Malcolm Taylor, Daniel Irwin

## 1. Introduction

Crossrail, currently Europe's biggest civil engineering project, is being built under central London to link existing Network Rail lines to the east and west of the capital. When it opens in 2018 it will provide rail services from Maidenhead and Heathrow in the west to Shenfield and Abbey Wood in the east.

Although significant remodelling work is required to the outlying Network Rail infrastructure and stations on both sides of the city, the most intensive construction effort surrounds the 21km of new twin tunnels under the centre of London, with several major new stations being built below ground, integrated with the existing London Underground (LUL) and Docklands Light Railway (DLR).

The project will increase London's below surface rail capacity by some 10%, and should lead to significant regeneration and development, both above the new stations' ticket halls and along the route. This will be a much-needed catalyst to growth. Crossrail will also provide a high-capacity fast direct link between Heathrow Airport, London's West End, the City of London, and the Canary Wharf business area to the east.

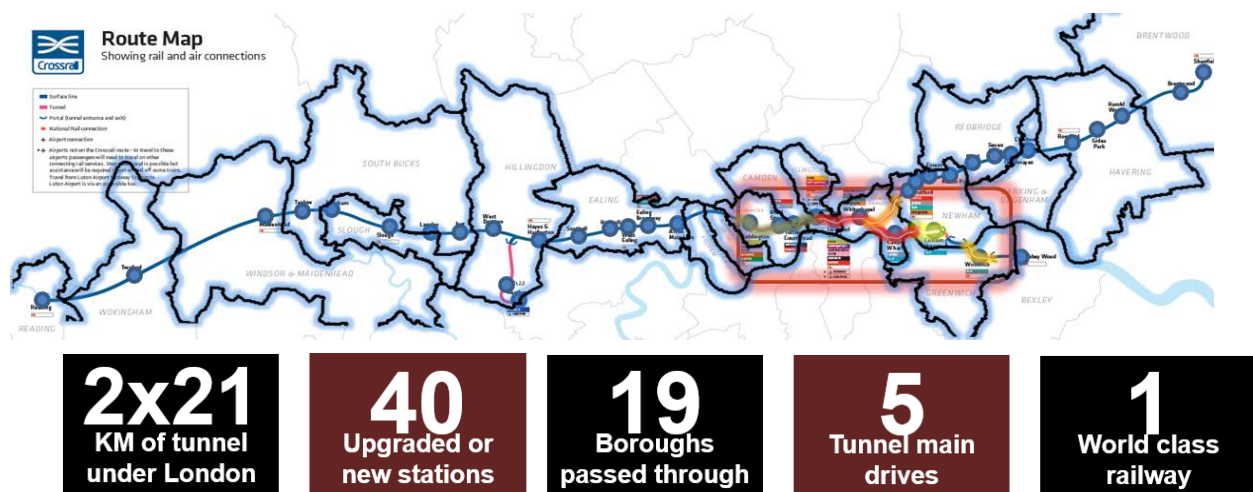


Figure 1: Overview: What is Crossrail?

## 2. Some of the Project Challenges

### 2.1. Engineering Complexity

Crossrail is unlike any existing underground railway in London. The 200m-long trainsets, their 10 cars potentially increasing to 12 cars, are the same size as those on Network Rail commuter and inter-city lines. They can carry up to 1500 passengers each, and the service provision is designed to deliver up to 24 trains per hour through the central underground section. As a result, the stations and ticket halls have had to be designed for a much larger throughput of passengers than any LUL scheme. Also, unlike previous schemes, the station ticket halls have been designed to permit future oversite development.

For example at Liverpool Street Station, as shown below, Crossrail interfaces with three existing London Underground lines and an ancient post office tunnel. The little square inside Finsbury Circus is the only green space within walking distance for the thousands of bankers, lawyers and employees in the City. Although the square will be completely refurbished after construction, it will remain closed to the public for seven years to allow for a temporary construction shaft to be built. This area, as well as other large construction sites at often overcrowded places in the heart of London need to be managed very carefully and require a high level of stakeholder and public engagement.

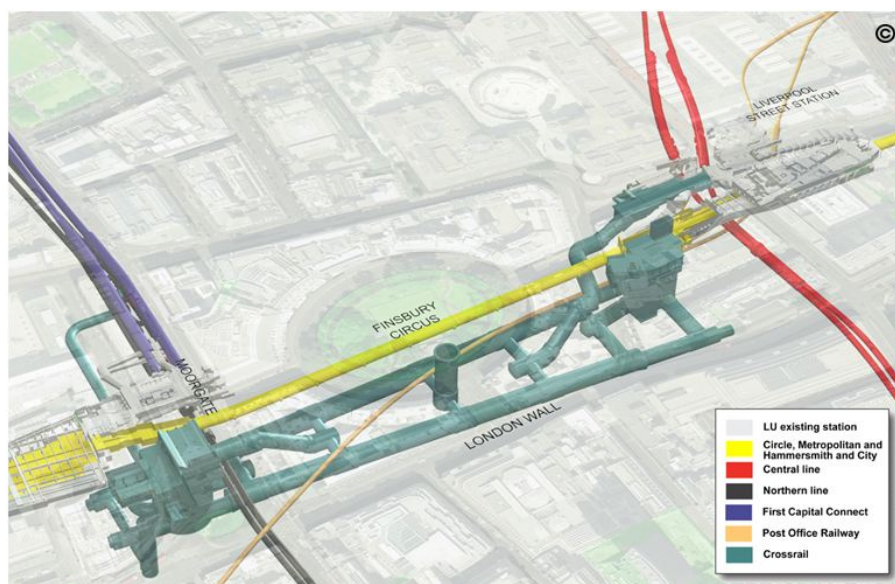


Figure 2: Engineering Complexity

This detailed design contract, awarded in June 2009 to the Arup-Atkins JV, is significantly more complex than its name implies. Arup-Atkin's responsibilities cover much more than the detailed design of all the segmentally lined tunnels on the project and rehabilitating the existing cut-and-cover Connaught tunnel for part of Crossrail's route under the Victoria and Albert Dock. The team is also responsible for the tunnel and track alignment, and the associated permanent way design. In addition, the package includes assessing settlement caused by all underground excavation along the central section from the bored tunnels, the sprayed concrete-lined tunnels for the platforms, shafts and station boxes, etc, together with assessing and mitigating the impacts of any settlement on all buildings and on other infrastructure (roads, Underground and overground railways, water, sewerage and gas pipelines, and underground power and telecommunications).

Finally, the scope includes developing the scheme design baseline from the MDCs of the

21km of tunnels between the interface boundaries with Network Rail, clear of the Royal Oak portal to the west and the Pudding Mill Lane portal to the east, and with the Network Rail surface network south-east of the Plumstead portal.

In places the tunnels are almost 40m below ground and had to be excavated through London Clay, the Lambeth Group, the Thanet Sands and chalk – and thus requiring TBMs capable of dealing with these materials on the various drives.



*Figure 3: Crossrail tunnel boring machine*

The overall aim is for the works to be constructed under London such that London barely notices.

To make things even more complex, Crossrail passes through the heart of London's West End and along the north edge of the Roman and medieval city. The archaeology programme therefore expects to uncover further important and interesting remains. Archaeologists have now discovered as many as 1,000 bodies at the London's St Bethlehem Hospital's former burial site near London's Liverpool Street station, as part of the capital's Crossrail development. Opened in 1247, London's St Bethlehem Hospital was the world's first institution dedicated to mental illness.

## 2.2. Project Management Challenges

The project, as every major project, has to be delivered to a very tight timeframe and budget. Hundreds of contracts needed to be procured, controlled and managed, lots of them with interdependencies between each other, which makes change management one of the key success factors of the project. For example every alignment change, driven by engineering requirements, triggers a chain reaction on the entire project. The land ownership and procurement team might need to purchase different parcels of land, the structural engineers need to assess different structures for potential damage caused by settlement, and the transport and logistics team might have to find different access routes to the worksites.

The numbers below give an indication of the challenging situation for the project management and controls teams.

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£14,800,000	Cost
2,385,380	e-Documents stored (46%) – so far!
1,000,000	Assets to be Tagged
321,147	Drawings (64%) – so far!
8,250	Individual Document users – so far!
650	CAD users – so far!
25	Main Construction contracts
8	Main Design contracts
2	Future Infrastructure maintainers
<b>1</b>	<b>Crossrail</b>

*Figure 4: Crossrail in Numbers*

### 3. What BIM means to Crossrail

It is important to appreciate that BIM is not simply about 3D models, and is not just about buildings, but about all infrastructure projects. Collaborative work is a core theme of the UK Government Strategy - and for an infrastructure project this involves convergence of Computer-aided design (CAD), BIM and Geographic information system (GIS) information with other types of project information, within a digital setting, such that the right information is available to the right person, in the right form, at the right time.

The key value to be gained from the adoption of BIM is the creation of a “digital Crossrail” that can be built “virtually”, which allows the design to be developed to improve and eventually optimise the design, construction, operation and decommissioning. When a Crossrail model has been built it can be used to support decision making and answer questions. The model has to be managed and leads to two potential uses of the M in BIM: modelling and management. The management of the model requires collaboration with all parties in the programme implementation including the supply chain as well as the operators of the railway. In the context of Government policy, the client organisations by adopting BIM will enable better optimisation of the asset being constructed.

For the implementation of that approach it meant, that an environment had to be created that supported:

- A defined end-game for data
  - Information requirements set out
  - Classifications and data structure
  - Procurement critical
- A Common Data Environment (CDE)
  - EDMS and ECMS
  - Used by everyone
  - Owned and managed by the Client
- Exploiting technologies e.g. databases
  - New defined roles and procedures
  - To BS1192
  - Deliverables and processes set out



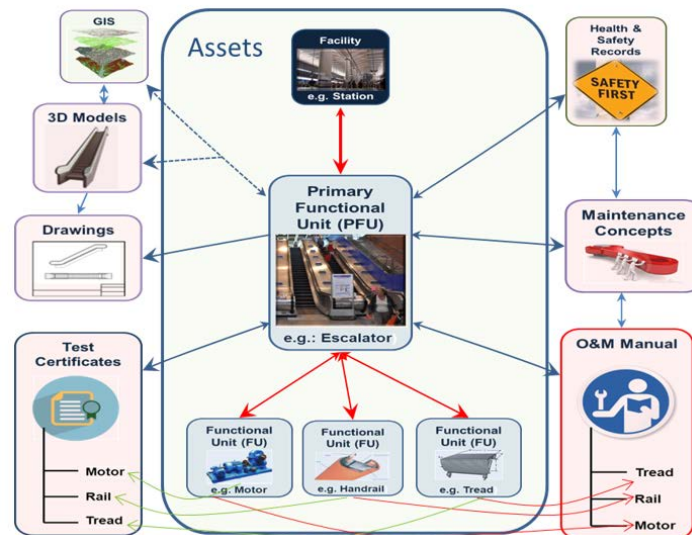


Figure 5: Key Characteristics of BIM

In summary, BIM means to Crossrail

- creation of virtual assets, not just physical ones,
- a set of processes that began some years ago,
- Integrates data for design, construction and operation life-cycles,
- Models the environment we want to build,
- collaborative management of all types of data,
- “Single source of truth”, which is a simplified term for integrated systems and data-bases.

Crossrail, as the client, the employer and the instance that sets the standards and requirements for the supply chain see themselves as an enabler for BIM. The aim is to create an end to end BIM process for Crossrail, which delivers value at any individual stage, with the highest proportion during the longest phase of the project's existence - it's operation.

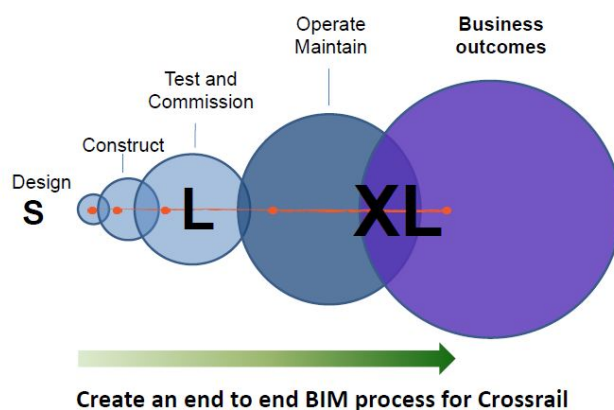


Figure 6: Business Outcomes

Crossrail had been well underway when the UK Government released the UK Construction

Strategy and the mandate for Level 2 BIM by 2016 in June 2011. However, back in 2008, an “Information and Data Management Strategy” had been fully implemented to ensure best practice in ‘Whole Lifecycle Information Management’; a combination of standards, methods and procedures, but also software, tools and hardware.

The role of lifecycle information management on the project was designed to:

- Reduce risk resulting from unmanaged or badly managed data
- Improve efficiency in workflows and data access through the implementation of spatial technology

The Data Management Strategy is based on the so called “BS1192 - Common Data Environment”, which forms one of the fundamental cornerstones in achieving the Level 2 BIM as defined by the Government’s BIM Task Force. Therefore it is fair to say that the project has been operating in a BIM environment long before the mandate for BIM was announced.

#### 4. Obstacles and how they were overcome

##### 4.1. Spatial Data Management and Integration

The Crossrail project aims for maximum integration of spatial data irrespective of its native format.

The array of engineering disciplines involved in the project include structures, geotechnics, tunnelling, noise and vibration, commitments, interfaces, and heritage. These all generate and demand a huge amount of information every day on a project of this size. In addition to this there is a vast amount of historical information, surveys, reports and drawings from previous stages of the project, generated or collated by other consultants. Other disciplines within Crossrail that require or generate information in relation to the design are for example the property and legal team, health and safety, help desk, estates management and many more. It is vital to the success of the project that data and information is readily available to all staff working on the project, and that it is reviewed and updated where new or more accurate information is found.

One of the biggest challenges on large infrastructure projects is the integration of the built environment and existing assets in the design process. This data is often available in native GIS format or in a structured format, i.e. csv or spreadsheets. All of this information has had to be made seamlessly available to the CAD departments in a 3D format to help create a unique 3D asset model.

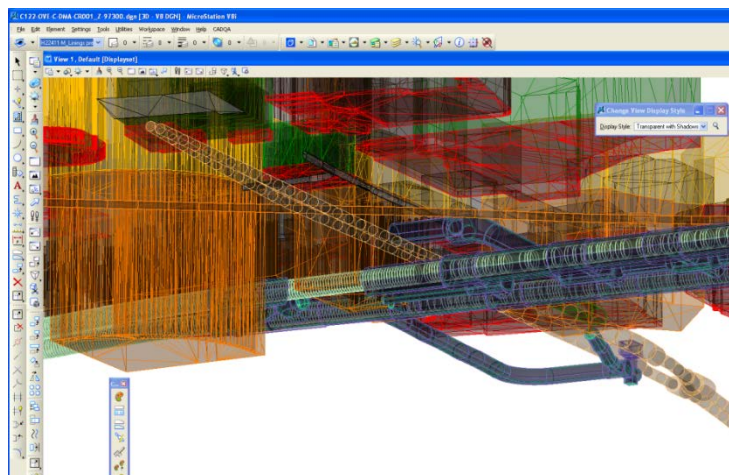


Figure 7: Spatial Data Integration in 3D – view from below ground

On Crossrail it was highly relevant mainly to the engineering disciplines to know where the existing assets, such as gas mains and utilities, deep building foundations or underground structures are in relation to the planned alignment of the Crossrail running tunnels. For instance, if the only information available to the project team is that there are more than 200 piled buildings along the route, but their locations are unknown, this information is of limited value. However if we are able to provide a location for each of the assets, along with other spatial information such as proximity to the running tunnel in both height and plan, and whether the asset is within the 10mm or the 1mm settlement contour, this information is of far more use. This meant that the design information had to contain far more than just 2D or 3D geometries and required proper GIS and CAD integration taking a data-centric approach.

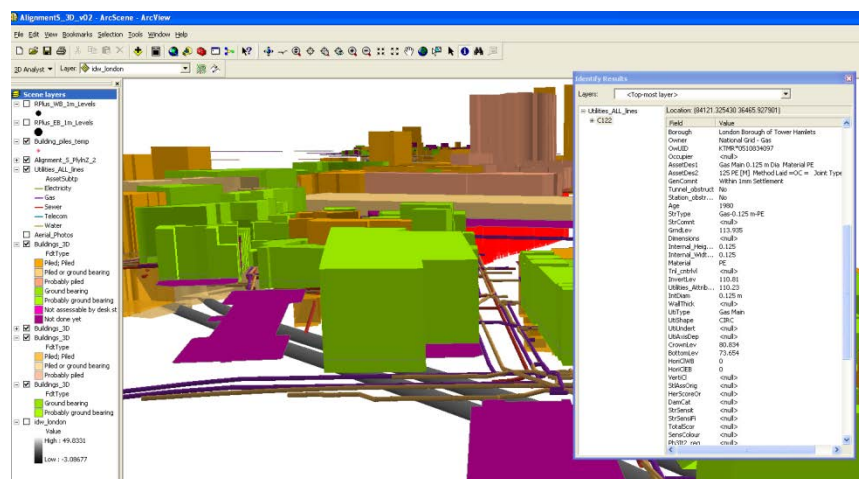


Figure 8: GIS, CAD, 3D CAD and BIM in a holistic approach

## 4.2. Tools and Systems Integration

The variety of systems, databases and tools that had to be linked up in order to achieve a seamless data and information flow comprised various brands of

- spatial and non-spatial databases (geotechnical database, land ownership, risk, mapping data, assets, etc)
- 2D and 3D CAD for design and drawing production
- Desktop GIS for analysis, visualisation, data management
- Web-GIS for data sharing and dissemination
- Office Applications for reporting, calculations, communication
- Specialist Software, i.e. for settlement analysis,
- Document Management System for Document storage and management
- Engineering Content Management System for drawing and model storage and management

As mentioned before, a lot of the criteria of level 2 BIM had already been written into Crossrail's 'Data and Information Strategy', the 'Data Management Guide' and the 'Requirements Strategy'. So called collaboration tools played an important role in achieving secure and efficient data and information sharing. In terms of data storage the project used two distinct, but linked systems for storing engineering content and documents. The BS1192-based workflow was fully implemented through the use of Bentley ProjectWise for all design drawings and models. With the deployment of Bentley's Enterprise Bridge another step towards Whole Lifecycle Data Management was done.

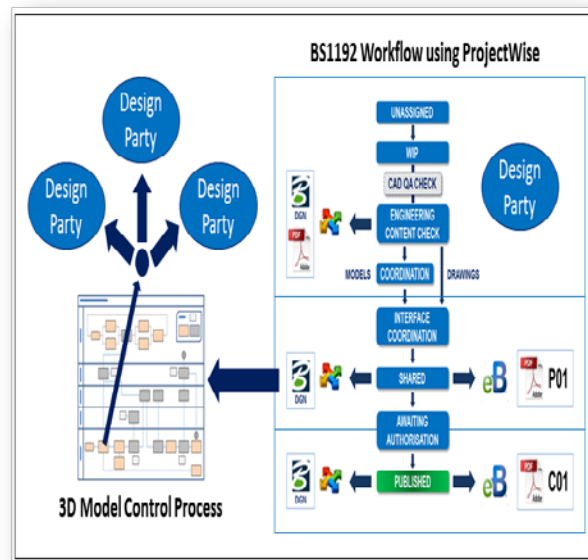


Figure 9: CDE Workflow implemented on Crossrail

As the project has grown, so has the variety in the data needed to be accessed. This wealth of information was, and is, required to be distributed to the entire project, on demand. Bentley Geo Web Publisher, known as Crossrail Maps, is now used to provide all of these requirements. It is a single mapping portal providing both mapping and metadata to the user's desktop through Internet Explorer. This provides direct real-time reading of data stored in ProjectWise. Leveraging the eB Application Program Interface (API) has also allowed Crossrail to expose and integrate information directly into the GIS arena, providing seamless data transmission across systems.



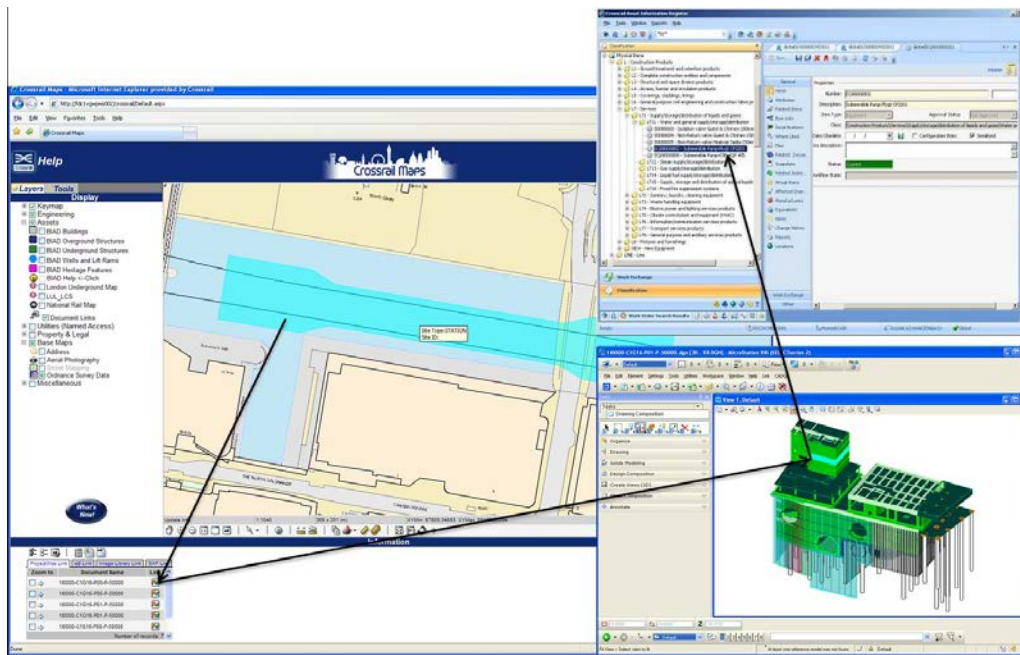


Figure 10: Web-based GIS for efficient access to data

## 5. Use of 3D Models

The spatial data model has had to incorporate the future requirements of asset capture and maintenance. From project inception Crossrail has designed with 3D in mind, be it Geospatial data or CAD information. In the asset capture / maintenance applications we link the disciplines together along with asset registry. In doing so we create a system where, through a simple singular interface, users can move from GIS data into BIM data through to asset information. The so called Information Modell is not yet fully object based and not linked to additional asset data. It is mainly used for spatial coordination, visualisation, construction sequencing and design validation.

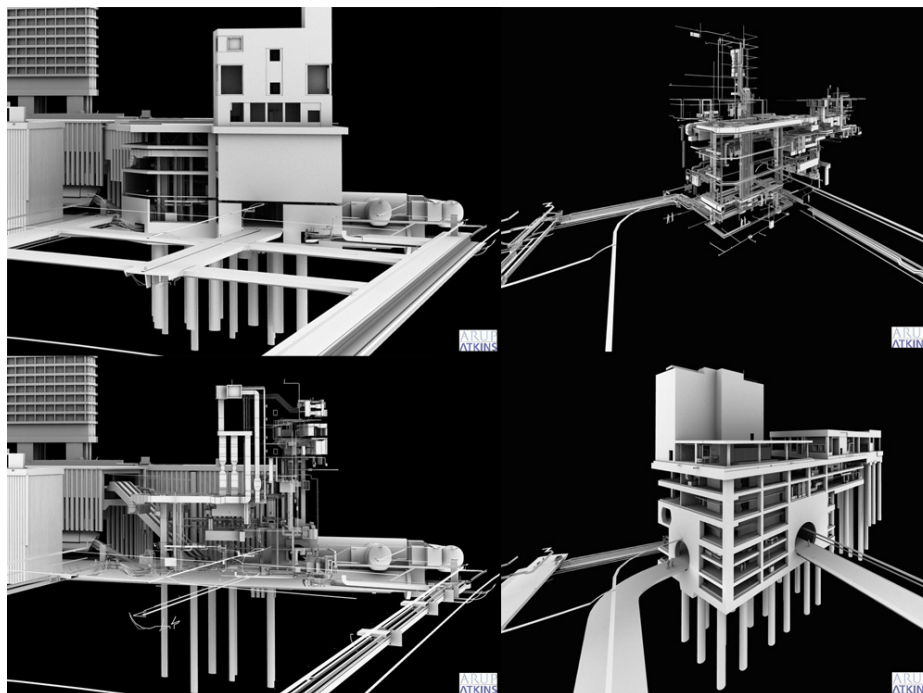


Figure 11: 3D Model examples

We observe on many construction projects that BIM outputs in defined format for attributes and quantities, i.e. the COBie format (Construction Operations Building exchange format) in the UK plus 3D models can only be achieved through the use of bespoke BIM software. This poses a constraint with regard to potentially expensive licences, a limited number of trained staff and proprietary databases within the software.

Crossrail used a different approach to object-based modelling as shown in the figure below. This approach is much more tailored to the actual requirements, which change over time from concept design over construction and commissioning to operations and maintenance.

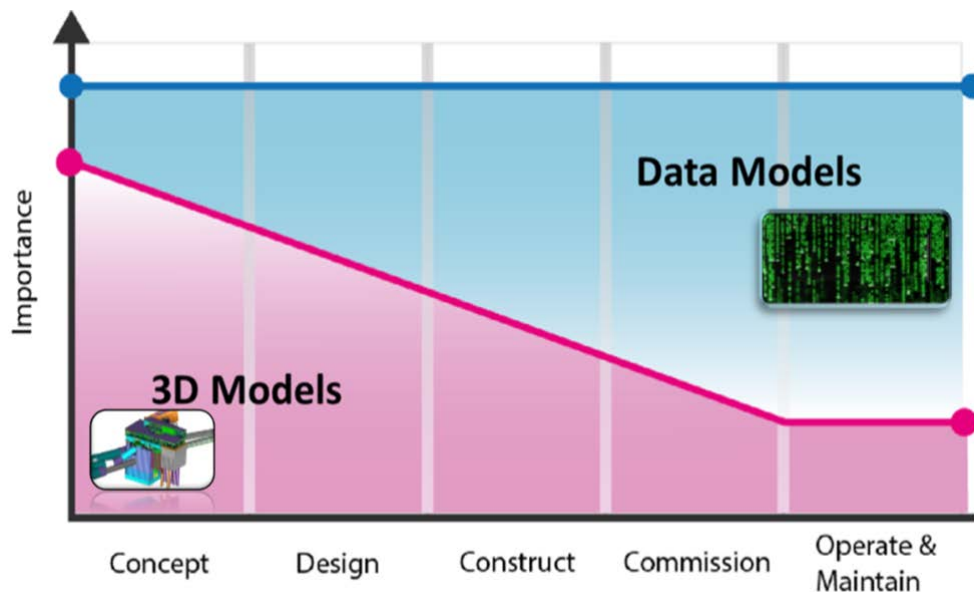
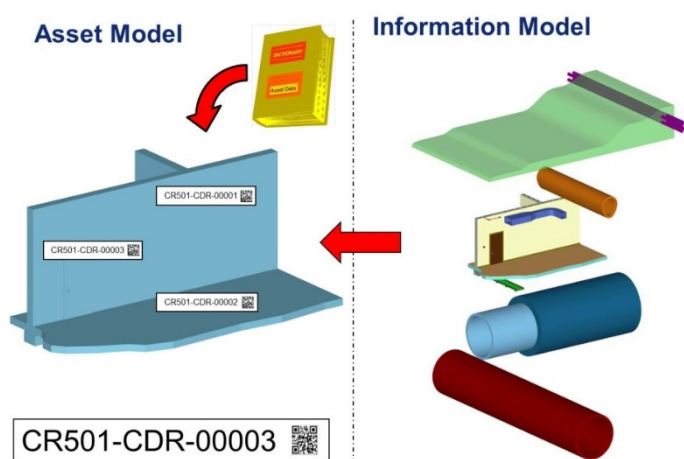


Figure 12: From 3D Models to Data Models

The assets with their respective parameters - Location, Function and Classification - are stored in the asset database and classified in the asset dictionary. Using a process called asset painting objects are generated in the 3D information model and assigned a unique identifier from the asset database. The process is demonstrated in the pictures below.

What Crossrail demonstrates is that object-based 3D modelling with added intelligence through unique IDs is possible.

Step 1: Converting the information model into an asset model



Step 2: Linking the asset model with the asset database. Objects on site are tagged with bar codes

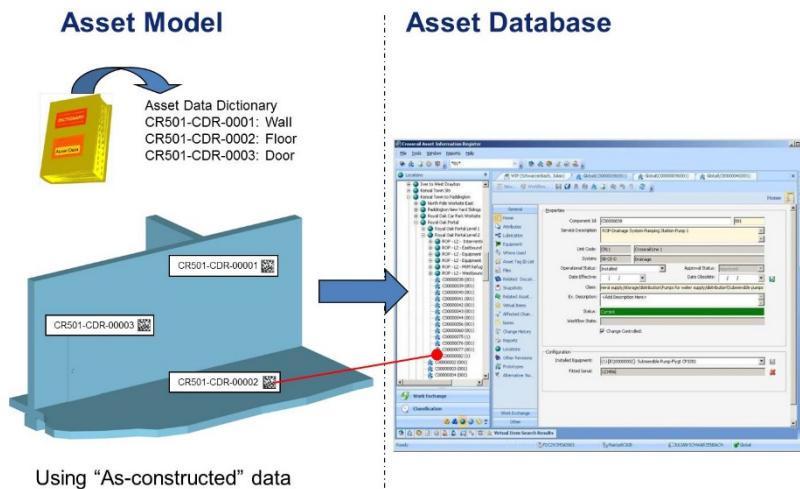


Figure 13: From 3D Models to object-based models

## 6. Conclusion

Summarising the above it is fair to say that there was no single technological innovation that made Crossrail so successful with regard to data and information management – in the same sense that BIM is not new either. An interoperable suite of software alongside fully embedded procedures based on industry standards were the key to Crossrail's success story.

The key lessons learnt are:

- Key principles:
  - Treat data as a valuable resource! (owned by the Client)
  - Establish your requirements (at business and project level)
  - Structure data with the end-use in mind – from the start
  - Good asset breakdown structure & classification - from the start
  - Use relational databases – from the start
  - Become data-centric (create a Common Data Environment)
- Beware (or mindful of):
  - Data interoperability (be prescriptive!)
  - Being led by IT!
  - People don't like change!