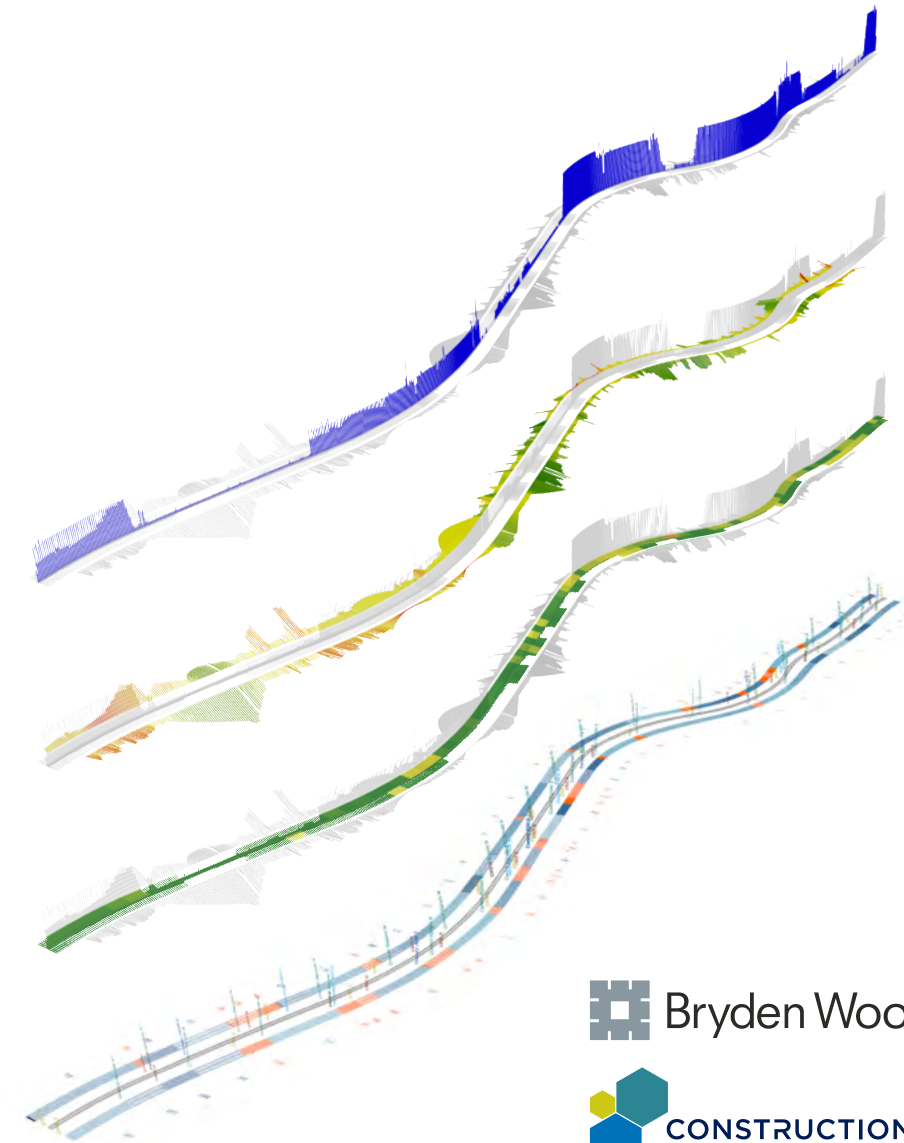
2017

Data Driven Infrastructure

From digital tools to manufactured components



Bryden Wood

CONSTRUCTION INNOVATION HUB

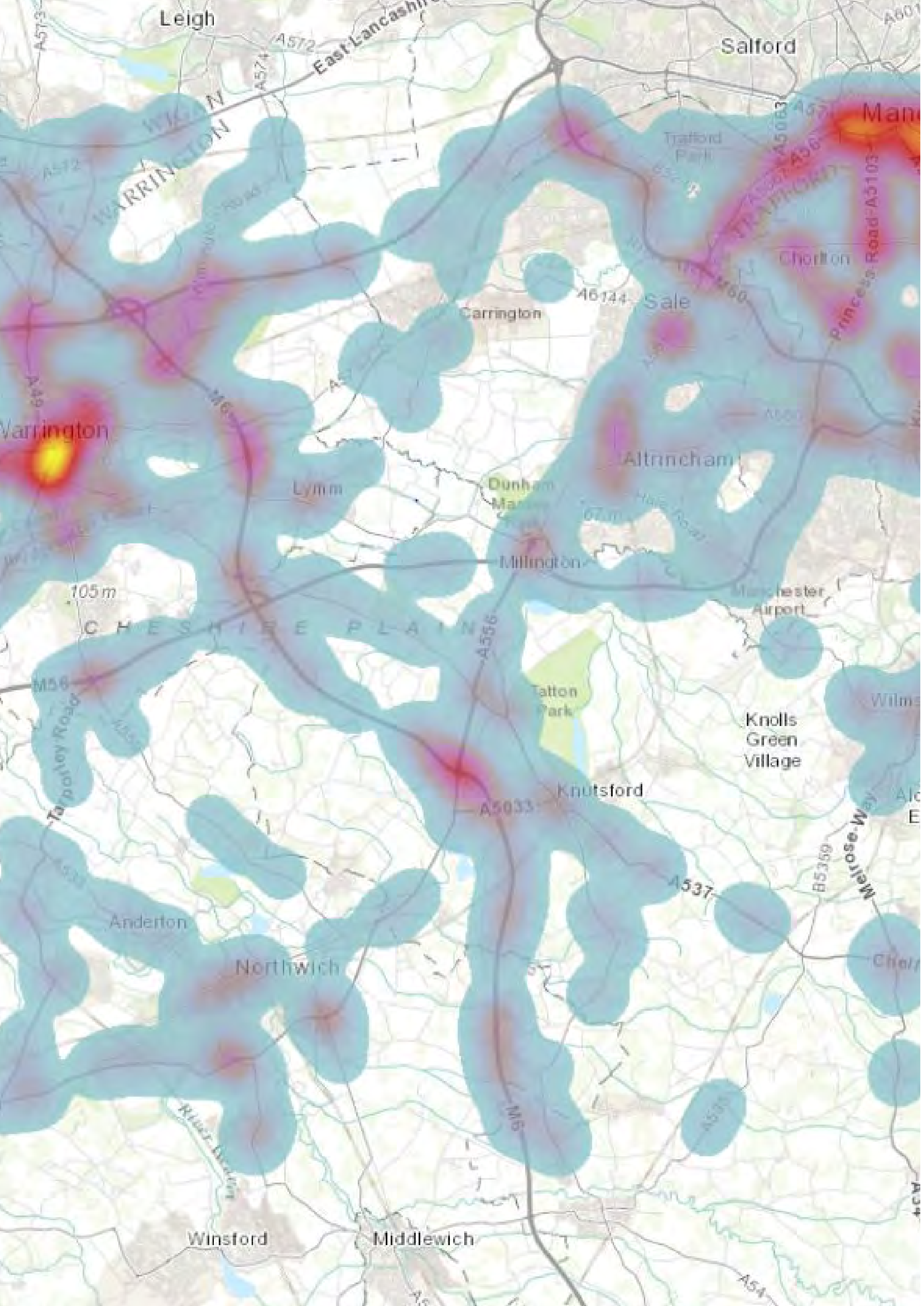


Table of Contents

1 Introduction
7 Project vs. Portfolio
15 Data analysis + visualisation
23 Parametric components
35 Rapid engineering models
41 Collaborative working
45 Classification
61 Component creation + configuration
69 Prototyping
81 Supply chain mapping
87 Training
95 Data-driven delivery controls

For other Platforms books + videos:

brydenwood.co.uk/perspectives/178/

Click on links for:

Bryden Wood

@brydenwood

brydenwood

@brydenwoodtech

Acknowledgements

This book was produced by Bryden Wood Technology Limited with input from Highways England, Crossrail, the Infrastructure + Projects Authority and the Manufacturing Technology Centre.

Version	Date	Changes
1	18.07.17	Initial issue for comment
2	20.07.17	Parametric process flows added. 'Configurator' updated

Introduction

Introduction

In July 2017 Digital Built Britain issued a document entitled 'Delivery Platforms for Government Assets - Creating a Marketplace for Manufactured Spaces' (see link / QR code on contents page). This set out a strategy for implementing the following vision:

Government will use the scale of its construction portfolio to help transform the market for creating high performing assets which improve the service for users, citizens and society and build a highly skilled and productive workforce.

It will improve the performance of assets towards international benchmarks, delivering enhanced quality, lower carbon and increased whole life value.

It will develop advanced manufacturing capability, products and services in the UK that could be exported globally.

The document described the strategic adoption of DfMA in a coordinated and consistent way across the Government estate, by setting out:

- The benefits of DfMA;
- The briefing and design process that would facilitate the adoption of standardised solutions;
- The characteristics that a standardised set of components (or 'Platforms') would need to possess;
- The methodology for assembly of assets that would maximise the benefits of an industrialised approach.

However, the book was primarily focused on buildings rather than infrastructure. Without duplicating the content above, this horizontal assets book highlights some current, relevant initiatives that are being deployed for clients including Highways England and Crossrail, that could be replicated as a standardised approach across a range of horizontal infrastructure projects in the highways, rail and water sectors.

Strategic aims

In order to reduce cost or programme, typical value engineering strategies are in fact exercises in reducing specification or compromising the design vision. Other cost reduction exercises focus on the supply chain, where savings of a few per cent may be achieved by squeezing suppliers.

The scale of Government procurement in buildings and infrastructure warrants a more informed strategy by truly understanding value and seeking to:

- Design solutions that delivers the maximum functionality for the minimum whole life cost;
- Develop standard, repeatable solutions that increase quality and certainty of delivery;
- Engage the supply chain in a way that facilitates continual improvement rather than constant reinvention;
- Protect supplier profit and overhead as these are positive aspects that support the wider economy and ensure that the project is seen as attractive to potential suppliers in a highly competitive market;
- Focus the time and effort of designers on the bespoke elements of projects while optimising the use of digital tools and standardisation to automate the production of repetitious information which is often resource-intensive but adds little value;
- Streamline the delivery process to create a high volume of quality information while deploying creative skill where it is most valuable; this could reduce or redistribute design fees while still providing profitable and creatively challenging work;
- Focus on reducing that proportion of the construction cost and programme that has no residual value but is related to risk, rework, and waste during the construction process.

The overall aim would be to improve productivity across the design, delivery and maintenance of the government estate by:

- Adopting best practice in design, procurement, manufacture, assembly and operation;
- Reducing rework and duplication of effort;
- Minimising waste and risk

Rigorously seeking to find the most efficient way of delivering a project inevitably reduces the resources required (whether this is measured in carbon, cost, time, waste or labour) while increasing positive aspects (health and safety, certainty, quality, morale, reputation and competitiveness).

The approach therefore seeks to:

- Ensure maximum integration of design disciplines;
- Reduce duplication of effort;
- Drive down total costs;
- Engage with the supply chain in a planned and timely fashion drawing on expertise and innovation where it adds value;
- Facilitate waste reduction through strategic and collaborative procurement using common components, material and construction processes;
- Blend highly standardised, mass customisable and bespoke elements together to create solutions that are finely tuned to suit context;
- Optimise the use of traditional, modular, flat pack and system build elements where they add the most value e.g. to maximise off-site labour where appropriate and improve the efficiency of in-situ construction;
- Facilitate deconstruction and flexibility through the creation of standard components which can be readily adapted to future changes in policy, regulations etc. (through interchanging elements, re-configuring or extending facilities) and eventually disassembled.

Project vs. Portfolio

Project vs. Portfolio thinking

As outlined earlier, the scale of government procurement allows significant value to be created through the adoption of programme wide approaches rather than considering a series of unrelated, single projects.

In a traditional, one off project, each asset is modelled, and information for design, tender and construction created individually. The design team can only afford to describe the proposed solution to a certain level of detail, which is then developed by the contractor in conjunction with their supply chain. Typically the degree of repetition at project level is low and only warrants highly detailed analysis of a few key areas.

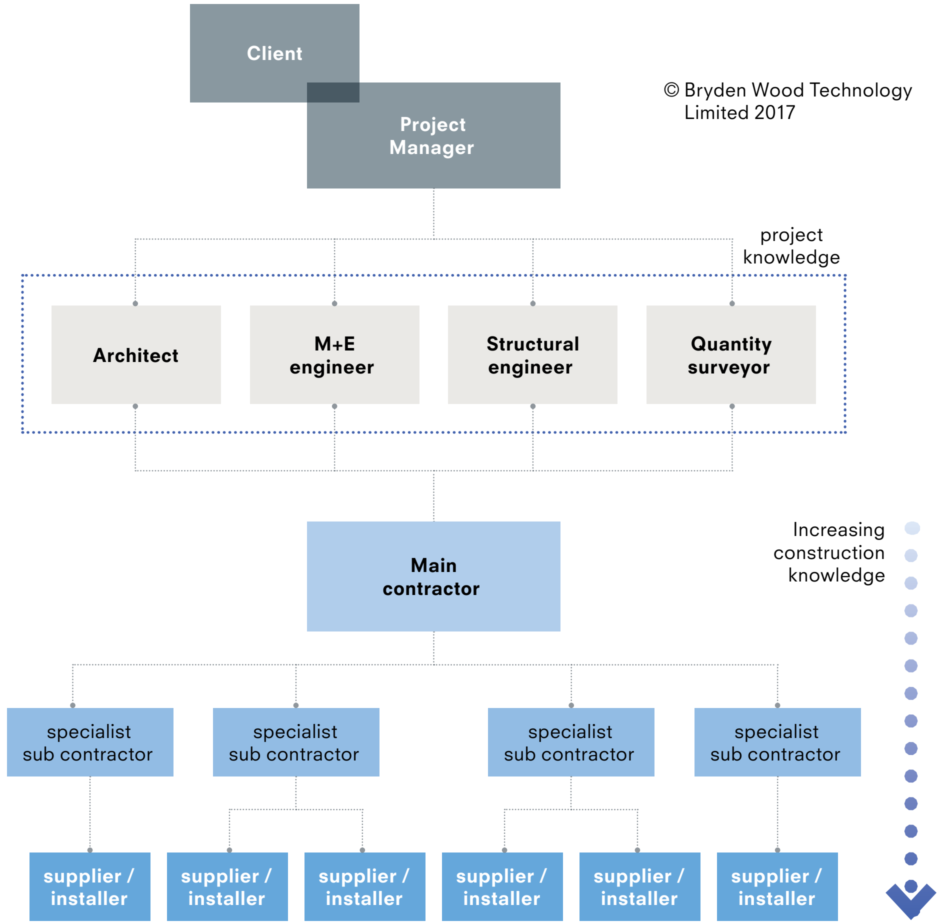
The fact that the design development (project knowledge) often takes place in isolation from the supply chain is a significant source of missed opportunities to optimise the design and leverage best in class construction knowledge.

In addition, most of the construction knowledge sits within the supply chain (see diagram, right) which may be fragmented and have little opportunity to collaborate. This is a significant source of rework and duplication of effort.

As a result, any benefits that are generated by innovation generally remain within the supply chain and are not passed on to the client for wider use. Any knowledge that is gained through the project cannot typically be captured, disseminated and improved upon to the benefit of other projects.

cont'd

Traditional procurement

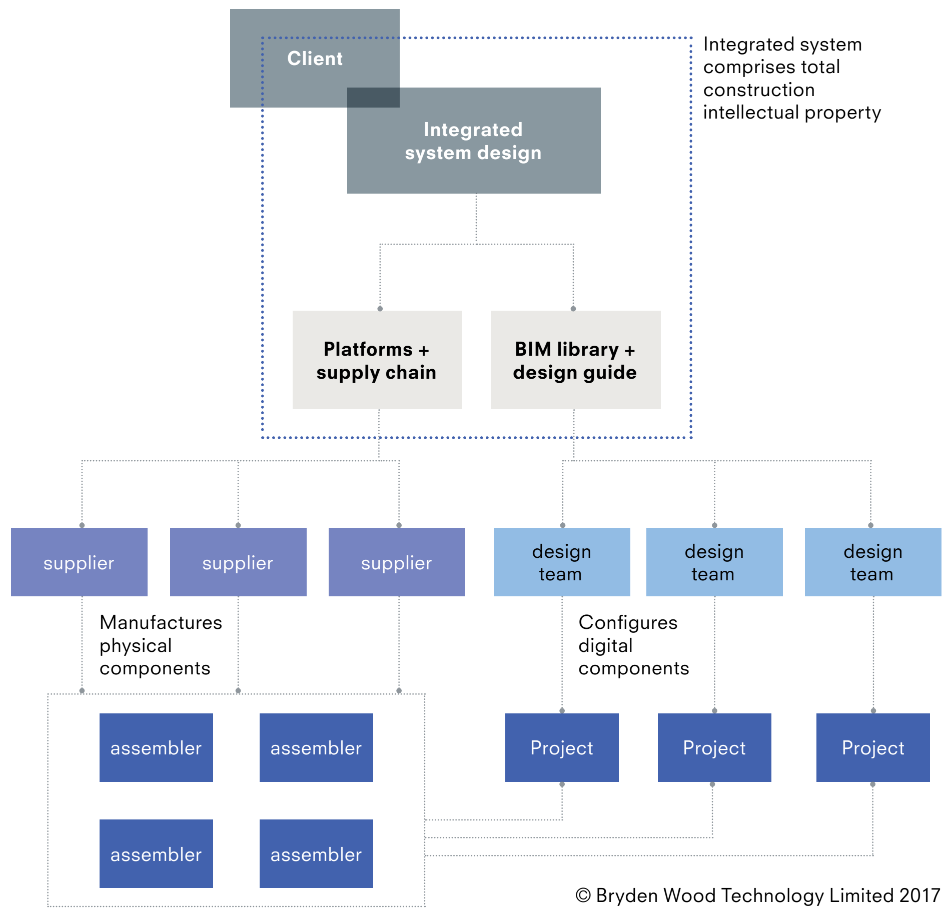


Project vs. Portfolio thinking cont'd

Considerable value can be therefore be generated through creation of a suite of standardised solutions and repeatable elements that are simply configured differently for different sites and project requirements.

Developing components for a large scale deployment, where knowledge is captured and retained for further collaborative refinement, would facilitate continual improvement (as is common in the automotive and aerospace industries) as opposed to constant reinvention (as is common in traditional construction).

Potential procurement route for an integrated programme-wide solution



The elements of the strategy

The productivity gains available through the adoption of platforms will be achieved (but will require appropriate levels of standardisation) throughout the project life cycle.

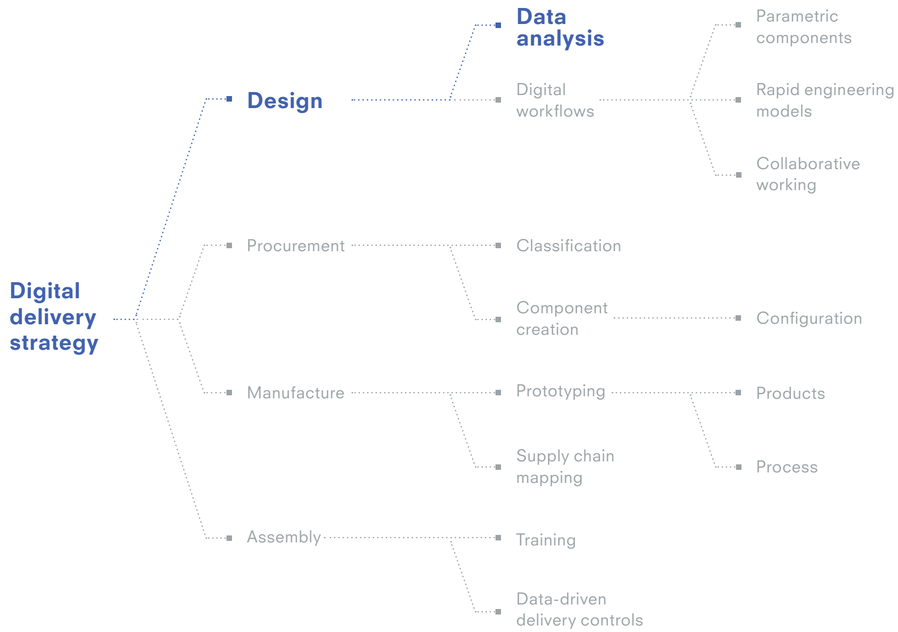
The remainder of the document sets out some of the key aspects of:

- Design
- Procurement
- Manufacture
- Assembly

Digital delivery strategy

- Design
  - Data analysis
  - Digital workflows
    - Parametric components
    - Rapid engineering models
    - Collaborative working
- Procurement
  - Classification
  - Component creation
    - Configuration
- Manufacture
  - Prototyping
    - Products
    - Process
  - Supply chain mapping
- Assembly
  - Training
  - Data-driven delivery controls

Data analysis + visualisation



Data analysis + visualisation

Building Information Modelling (BIM) is, fundamentally, a collaborative way of working that is powered by digital technology.

By optimising the use of the existing governmental department BIM libraries, enhanced with components specific to the early platform developments, there will be a huge amount of cross-programme data available through site-specific models uploaded to the Common Data Environment (CDE).

Data visualisation allows a range of data sources to be brought together to inform strategic planning and decision making. These visualisation techniques work at a variety of scales, so certain techniques allow whole project analysis, while others allow the optimisation of individual components or assembly processes.

By creating highly detailed data sets (dealing in, for instance, numbers of individual components and activities rather than square metres of floor area) the level of transparency and control is dramatically increased.

Aggregating data from multiple sites into a single, project-wide view provides clients with a level of insight that was previously unattainable.

For instance, visualising interaction between various work-faces so that knock effects of delays in one area can be better understood, facilitates:

- A more holistic view of project-wide progress;
- Strategic prioritisation and optimisation of work faces / packages;
- Smoothing of cash flow or labour;
- Smoothing demand for individual components through just in time delivery, reducing stress on the supply chain, enhancing their productivity and therefore lowering price;
- Optimisation of resources by understanding how operatives and plant can be shared.

cont'd

Day light

Darkness: street lights present and lit

Darkness: street light present but unlit

Darkness: no street lighting

Darkness: street lighting unknown

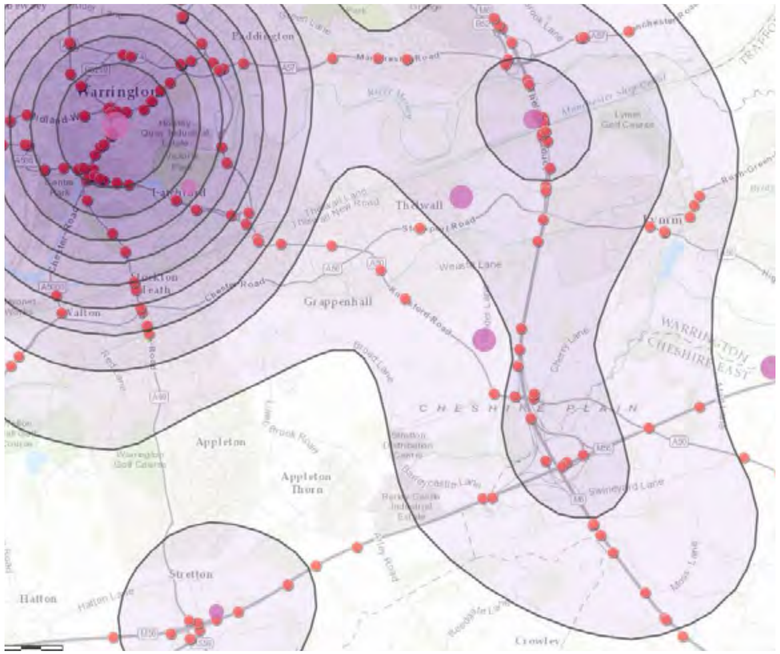
Output from a data aggregation and visualisation exercise for Highways England

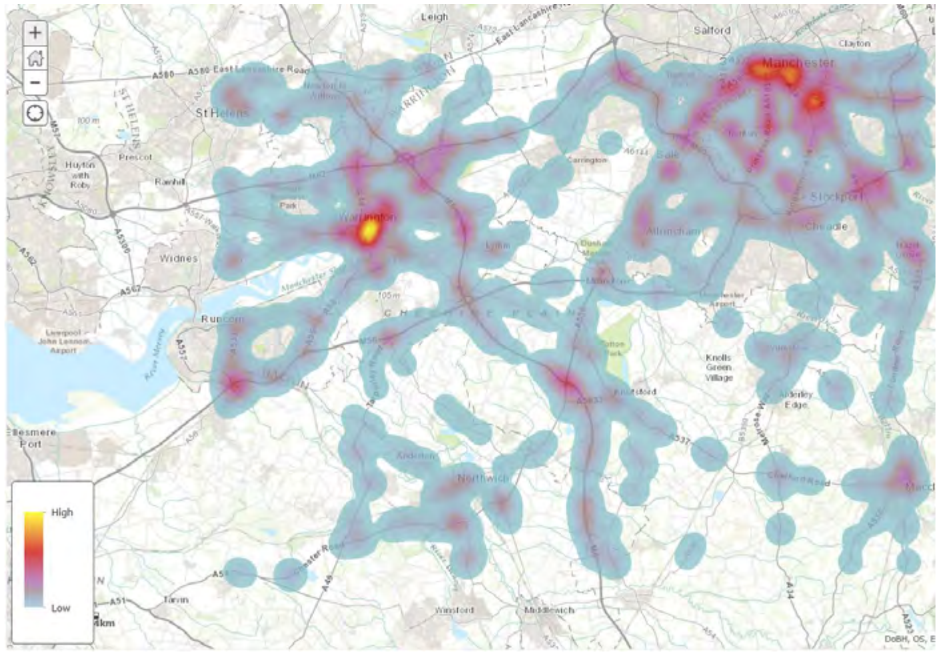
Data analysis + visualisation cont'd

Other example uses include:

- Colour filtering of models to create heat maps show the intensity of trade overlap, cost per hour of installation etc.;
- Allowing multiple stakeholder views to be combined, addressed and prioritised;
- Allowing the interdependency between a range of factors that impact productivity to be understood;
- Providing a single point of entry to a wide range of digital content.

Output from data aggregation and visualisation exercises for Highways England





GIS enabled BIM

The nature of large infrastructure projects, particularly horizontal infrastructure including rails and highways, necessitates the use of both GIS (geographical information system) and BIM technology and data, on a day to day basis.

GIS systems typically provide the capability to overlay nation wide or network-wide geo-spatial 2D data, while BIM is more typically used for project-specific 3D design and construction models.

A pilot project for Highways England as demonstrated the power in treating these as complimentary digital platforms, rather than as discrete systems.

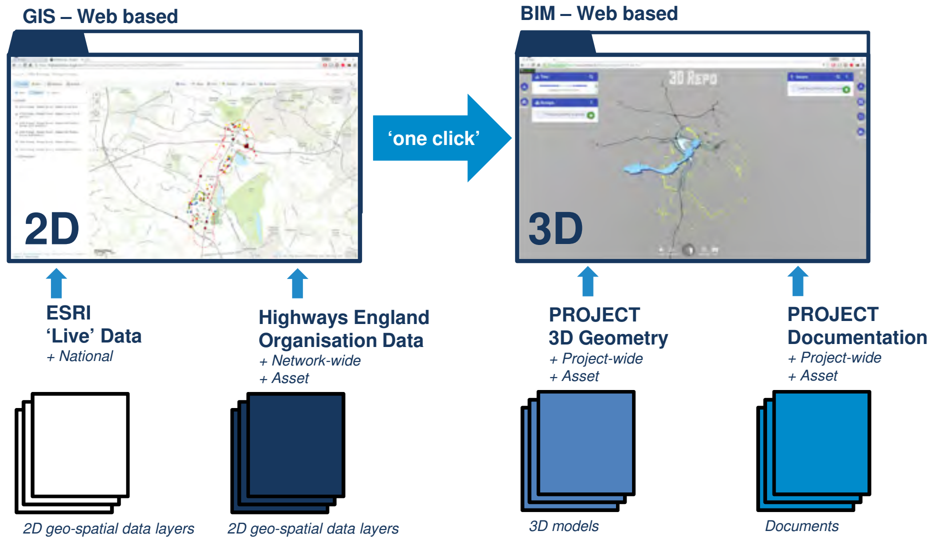
As part of this project, a range of Data Layers were collected and collated in both the GIS and BIM platforms.

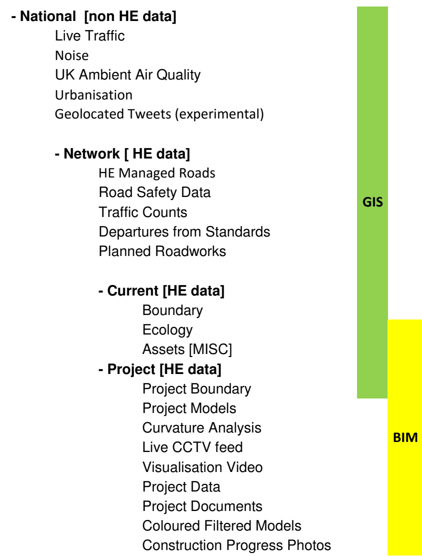
This approach used existing data sources that are held by Highways England (in some form or another), open source data sets published though UK Government portals or data otherwise accessible directly through the software platforms being used.

The project provided users with a '3 clicks or less' navigation experience to travel from network-wide GIS data, down to the construction detail component level typically held within a BIM model.

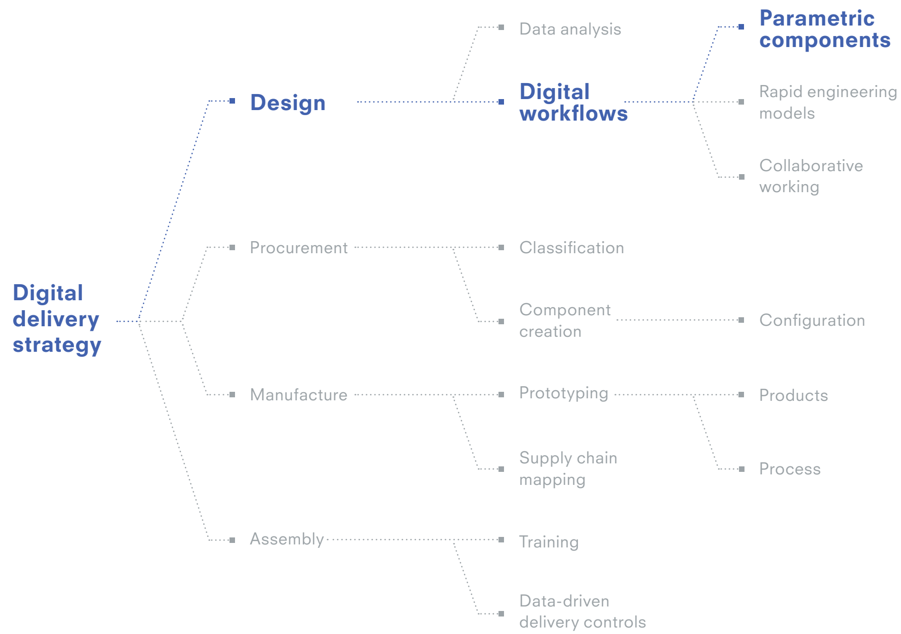
This approach helps target effective interventions in their programme of works by:

- Providing a single point of entry to a wide range of digital content;
- Allowing multiple stakeholder views to be combined, addressed and prioritised;
- Allowing the interdependency between a range of factors that impact network operations to be understood;
- Demonstrating client benefit for network Operation, Construction and Maintenance;
- Providing users with new perspectives on digital content within Highways England and other infrastructure clients.





Parametric components



Component libraries

In autumn 2015, the first initial version of the Highways England BIM library was developed.

It is worth noting that the library contains plant and vehicles commonly used in construction and maintenance. This allows a number of scenarios to be tested as part of the collaborative modelling workshop described later in this document e.g. ensuring that safe access and operational efficiency can be demonstrated throughout the life cycle of a proposed asset.

The components are arranged in aisles comprising:

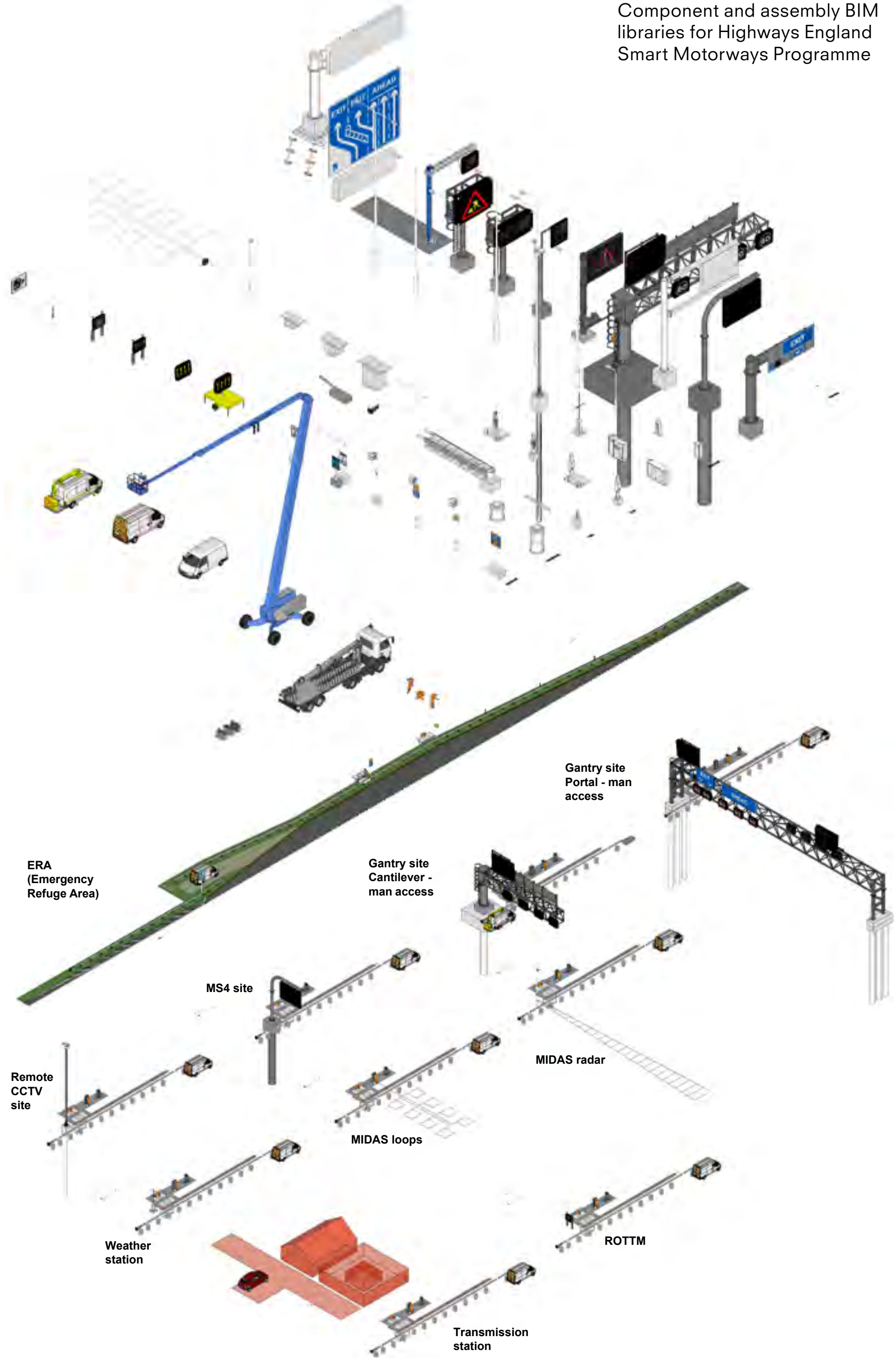
- Vehicles;
- Small signage;
- Vehicle restraint systems (VRS);
- Technology (communications);
- Electrical (including lighting);
- Large signage;
- Road markings;
- Road sections;
- Gantries.

The components have then been grouped into assemblies to optimise the design process and ensure that all elements of a proposed asset are considered.

Assemblies include:

- Refuge Areas / Emergency Refuge Areas (ERAs);
- Gantries and associated signage;
- Central reservation;
- Remote CCTV Site;
- MS4 Site;
- MIDAS - Loops;
- MIDAS - Radar;
- Transmission Station;
- ROTTM;
- Weather Station.

Component and assembly BIM libraries for Highways England Smart Motorways Programme



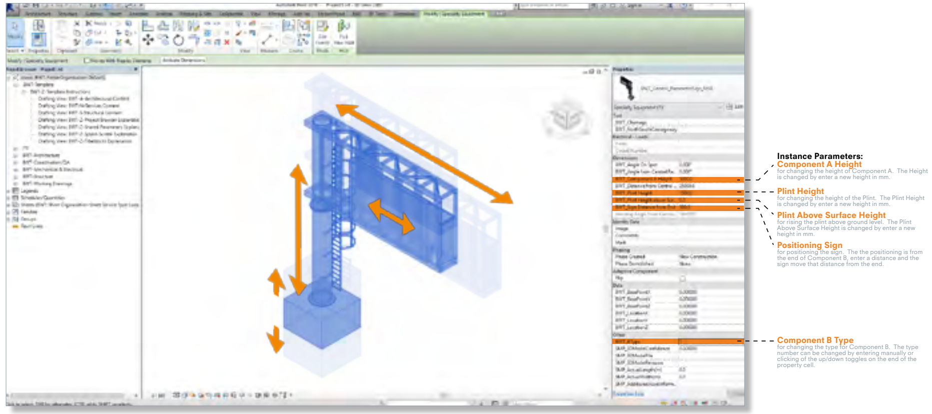
Parametric assemblies

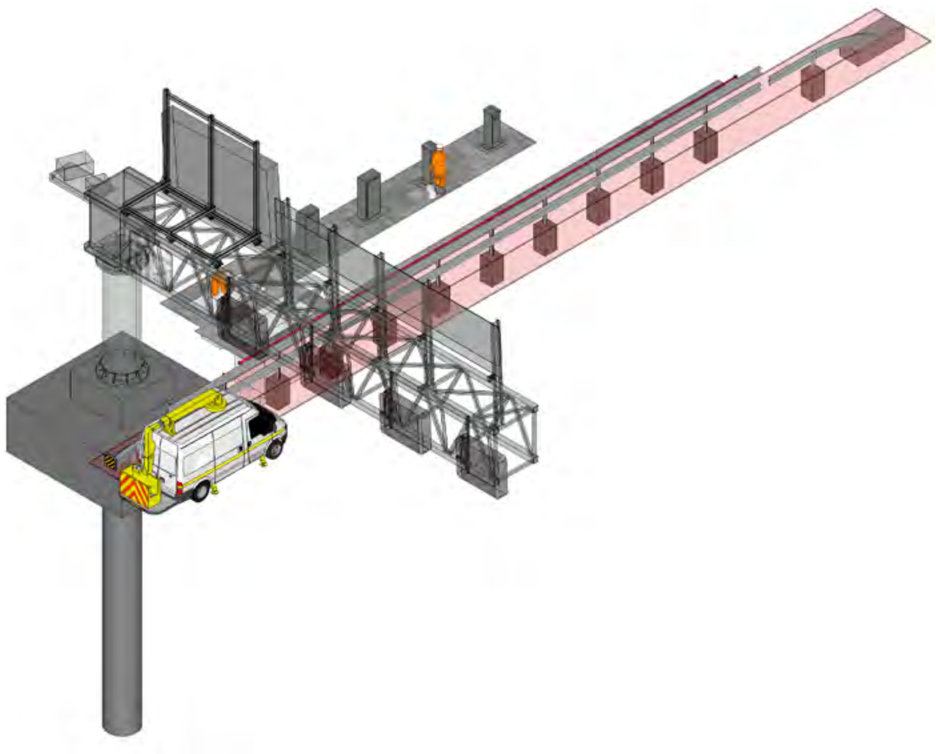
The assembly models have been developed with a number of key features that increase their functionality and dramatically improve productivity during the design process:

These include:

- Inclusion of information from all parts of the assembly life cycle e.g. exclusion areas, personnel and equipment for maintenance activities are included within the model to ensure that these are allowed for in the design phase;
- The geometry is highly parametric so as the assemblies are dropped into a base model they will automatically adapt to the curvature of the road, local topography etc.;
- The parametric geometry extends to individual structural elements allowing assemblies to be considered as families of components that include minor adaptations to localised context.

Parametric components, created in this way facilitate the adoption of mass customisation, whereby the benefits of a standard library of BIM objects can be allied with the benefits of context-specific bespoke design.





Example parametric assembly - gantries for Highways England Smart Motorways Programme

Parametric process flows

For many clients the cost of equipment and personnel, operational and maintenance costs and the business or social outcome related to a particular process are many times greater than the capital cost of the facility which houses the process. As a result time spent in designing and optimising the process can yield enormous benefits over the life cycle of an asset.

The use of visual scripting tools allows highly parametric models to be created for complex processes; this is currently used in process flow facilities for pharmaceuticals etc. but could readily be applied to e.g. water treatment processes.

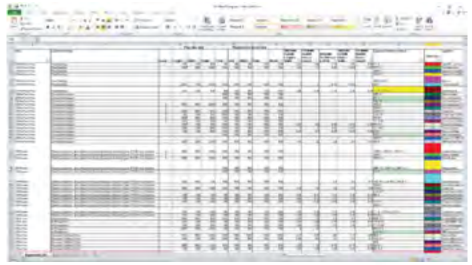
In the first instance, existing process flow diagrams (PFD's) or piping and instrumentation diagrams (P&ID's) are replicated using visual scripting which allow rules and interdependencies to be captured.

This allows complex processes to be shown as a series of linked objects (which may represent pieces of equipment or steps in the process). By changing parameters (e.g. flow rates, equipment capacities, distances or links between pieces of equipment) the srrounding context will automatically flex to suit.

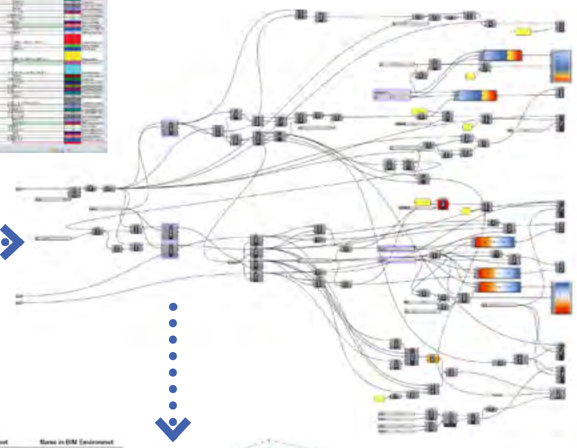
This allows multiple options to be tested or, even more valuably, new processes to be virtually tested and optimised with a very high speed of iteration and allowing for a great deal of variance between the 'known' and 'unknown' aspects of a process.

Interdependencies between multiple processes can be simulated, allowing complex facility models to be developed and tested.

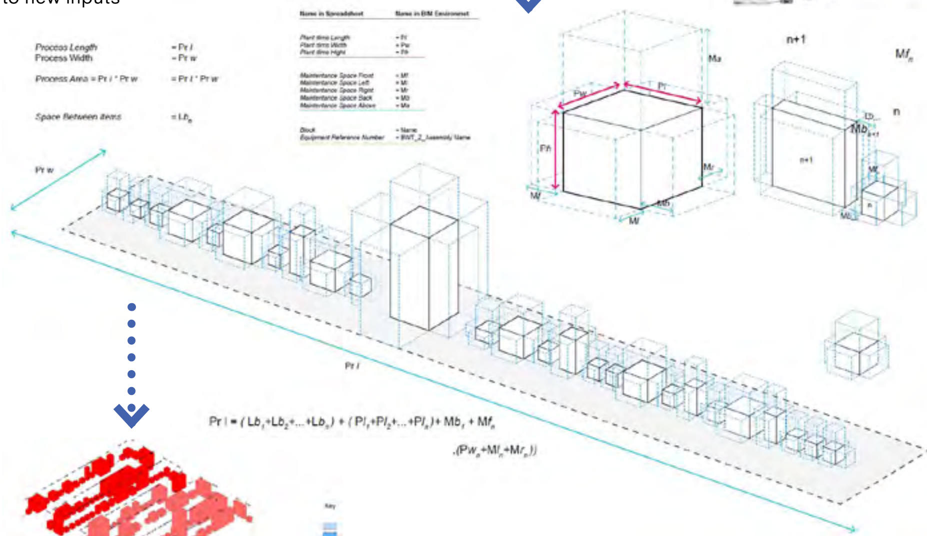
By linking these parametric models to BIM authoring software facility design becomes at least partially automated (particularly if standardised components are used as advocated in 'Delivery Platforms for Government Assets') leading to significant increases in productivity and the efficiency of assets.



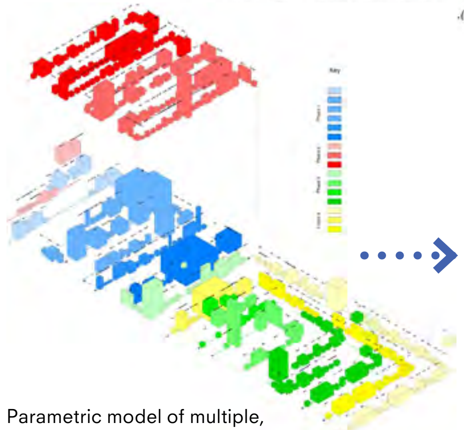
Process flow initially captured in spreadsheet format



Process flow rules and interdependencies captured using visual scripting



Parametric outputs which automatically flex in response to new inputs



Parametric model of multiple, linked process flows

BIM model generated automatically from parametric flow models

Mass customisation

Mass Customisation is a manufacturing technique that combines the flexibility and personalisation of custom-made products with the low unit costs associated with mass production.

As described above, automotive manufacturing is an example of a successful implementation of this approach; computer manufacturing is another. Both of these sectors are characterised by the capability of the suppliers to provide customers with a personally configured product, with seemingly limitless possibilities of configuration. Neither party suffers significant additional cost or inconvenience for incurring such choice. In fact, the opposite is true.

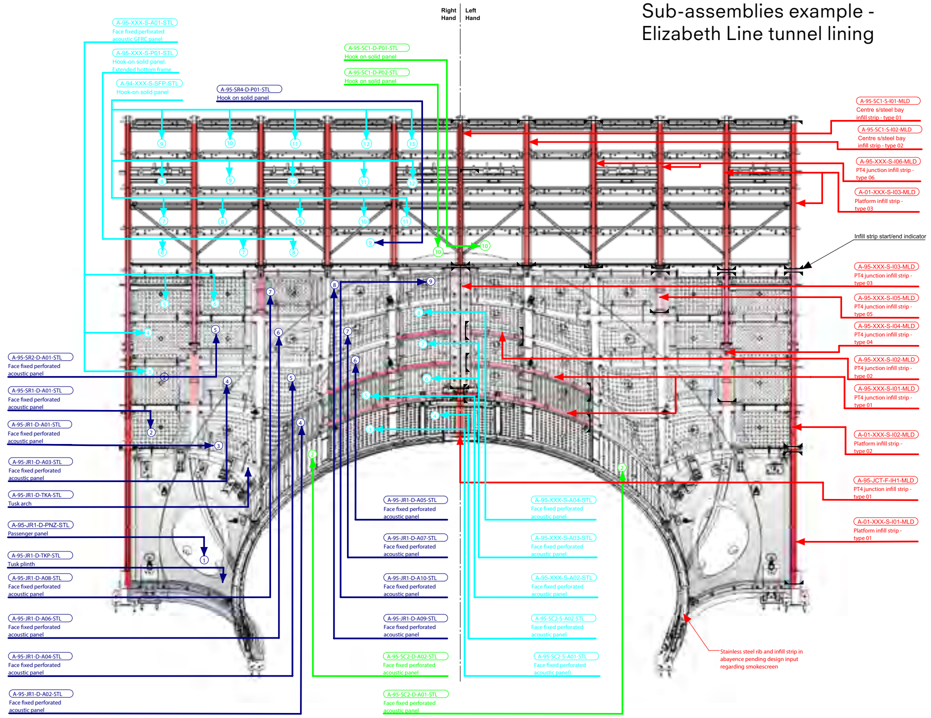
In order to provide solutions that are fine tuned to specific localised needs and contexts, the creation of delivery platforms should accommodate sufficient levels of mass customisation.

In order to achieve these outcomes, consideration will be given to a number of scales;

- Product assemblies - Market testing to find popular or typical product configurations, as well as the likely appetite for variation and deviation from these baselines. The requirement for product assemblies will be created by the spatial design work streams and a more detailed analysis of the make up of the existing and planned government estate according to the characteristics described above;
- Sub-assemblies - Comprehensive understanding of relationships between component parts, such as their interoperability as of part of larger assemblies. This includes the details of the specific assembly processes that are required;
- Component parts – Identification of a parts library, that can populate the sub-assemblies and combine to deliver the performance requirements of the product assemblies. This includes detailed knowledge of parts such as performance, costs and availability.

cont'd

Sub-assemblies example - Elizabeth Line tunnel lining

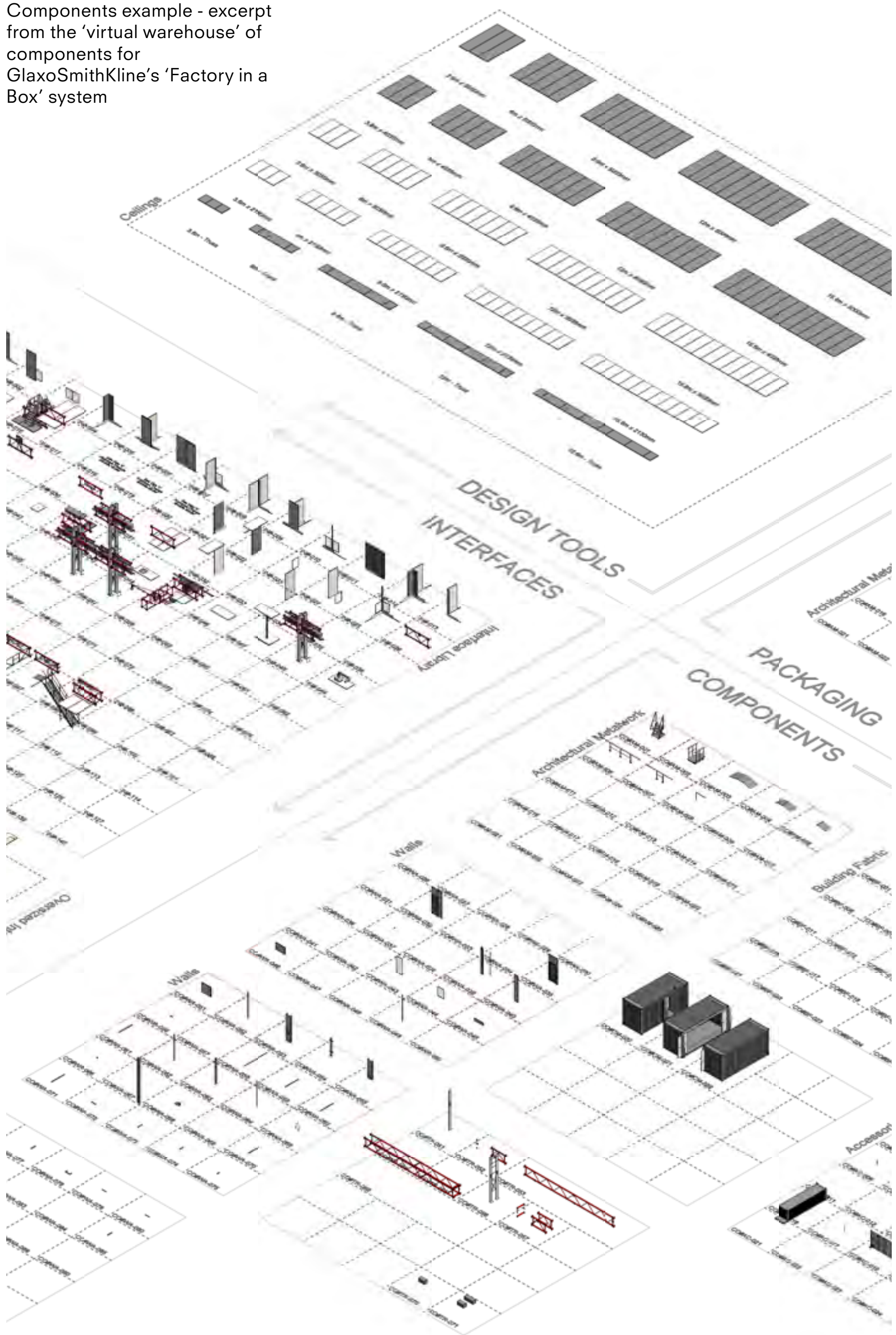


Mass customisation cont'd

This strategy will apply the thinking that underpins existing, successful models of mass customisation to the building design and construction industry and will take on each of these three work strands in order to determine and document;

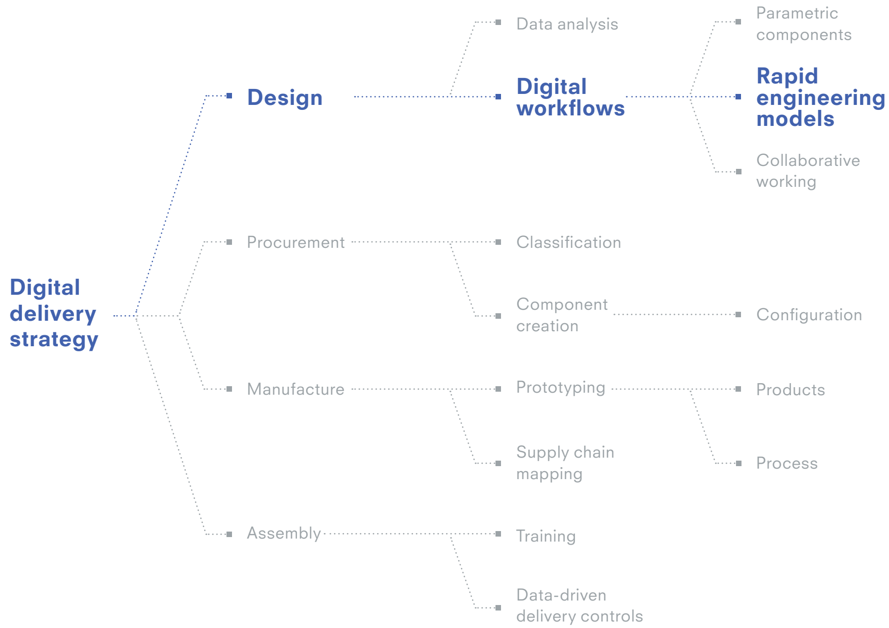
- Product assemblies – Identification and documentation of the functional typologies of spaces, departments and facilities that define publicly procured built assets across the most high value sectors. This work strand will provide briefing and guidance for the further work necessary to standardise and optimise spatial configurations across typologies;
- Sub-assemblies – Identification of common constructional and operational Sub-Assemblies that can serve multiple typologies. This will include architectural, structural and MEP systems. This workstream will provide briefing and guidance for the further work necessary to standardise and optimise sub-assemblies to suit the Product Assemblies;
- Component parts – Identification and documentation of common component parts that can serve multiple Sub Assemblies. This work strand will provide briefing and guidance for the further work necessary to create a standardised 'parts library', including the means of cataloguing criteria for verification and validation required for maintaining it.

Each of these three strands will be underpinned by the use of BIM Level 2 standards, and in particular the use of Uniclass 2015 as a classification system to capture facilities, spaces, systems and products (this is described in more detail in the next section).



Components example - excerpt from the 'virtual warehouse' of components for GlaxoSmithKline's 'Factory in a Box' system

Rapid engineering models



Rules-based context analysis

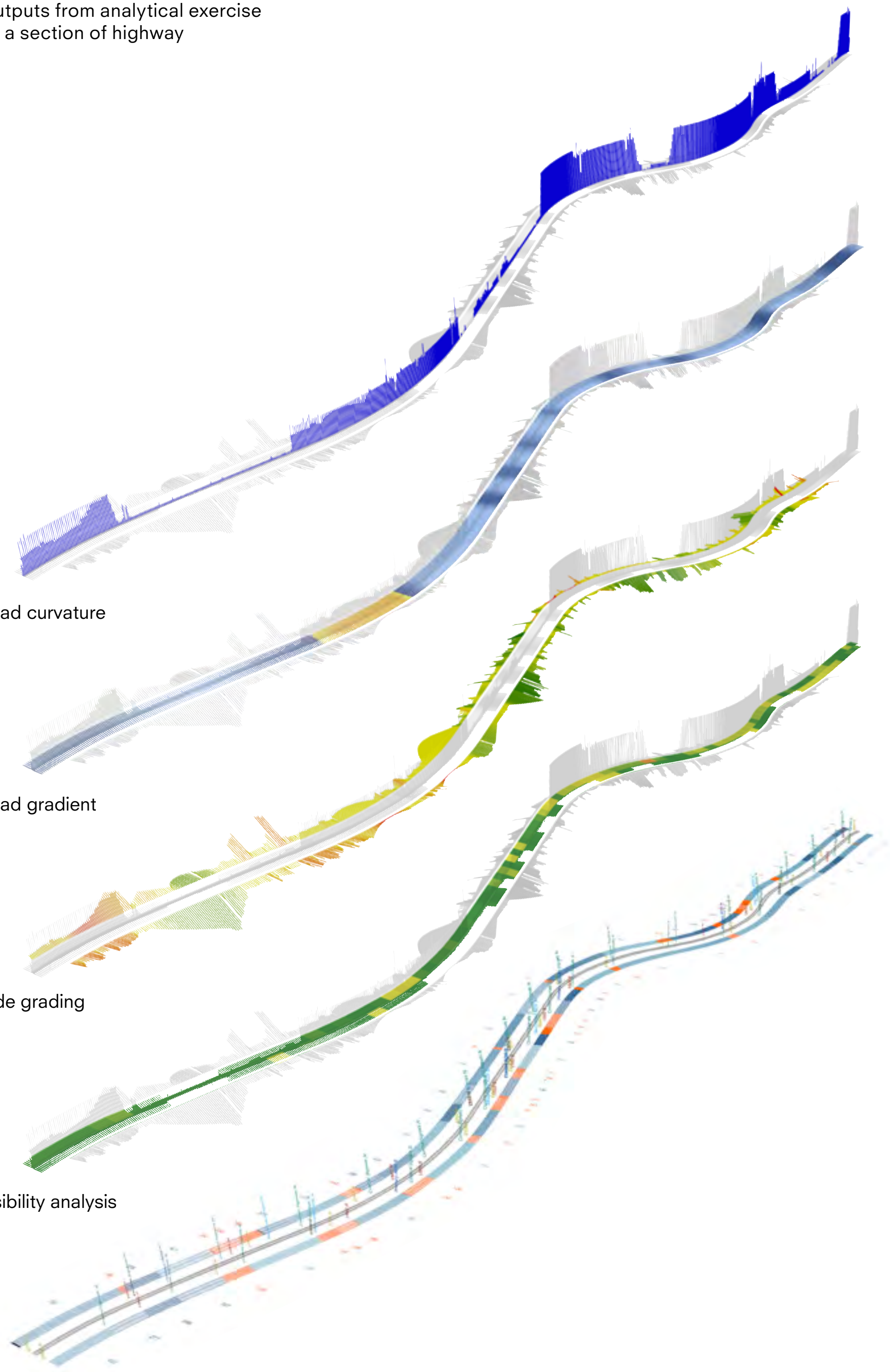
The parametric models described in the previous section are a key enabler of self-generating rapid engineering models.

Site survey data is first analysed by running automated workflows relating to a number of specific conditions.

The examples on the opposite page show analysis of a section of motorway, analysed according to:

- Visibility;
- Gradient;
- Curvature;
- Verge condition.

Outputs from analytical exercise on a section of highway



Road curvature

Road gradient

Side grading

Visibility analysis

Assemblies density

Rapid engineering model

The outputs of the analysis will then dictate the placement of certain features or assemblies.

Because the parametric assemblies can be enriched with rule sets governing visibility distance, maximum distance between components, interaction with other assemblies etc. the base context model can be automatically populated.

The example on the right shows the rules sets for one type of assembly, plus a sample populated model.

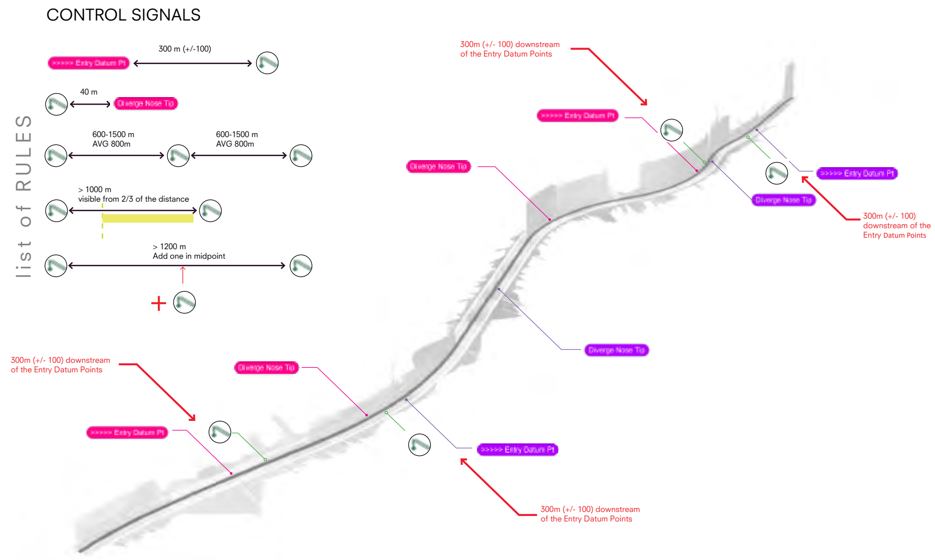
This rapid engineering model includes:

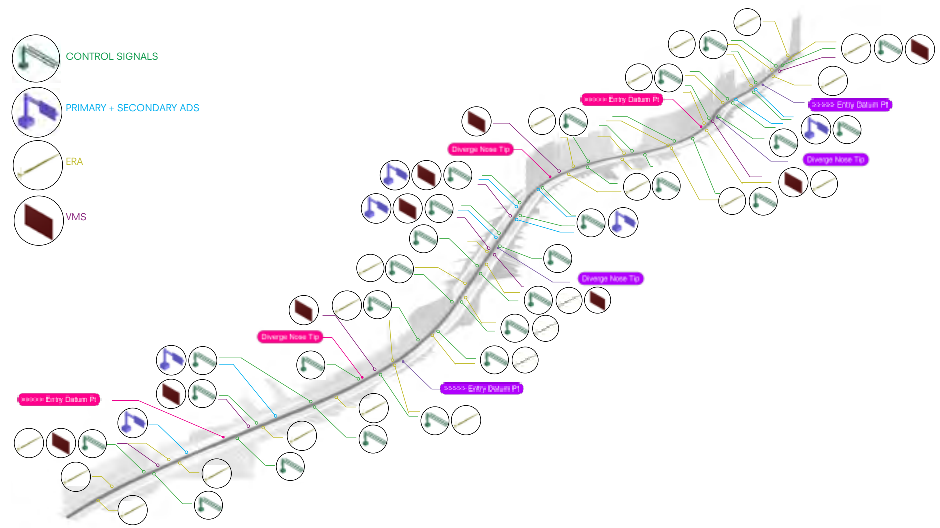
- Preliminary assembly positions, based on design guidance rules only;
- Assemblies at LOD4, LOI4.

Outputs include:

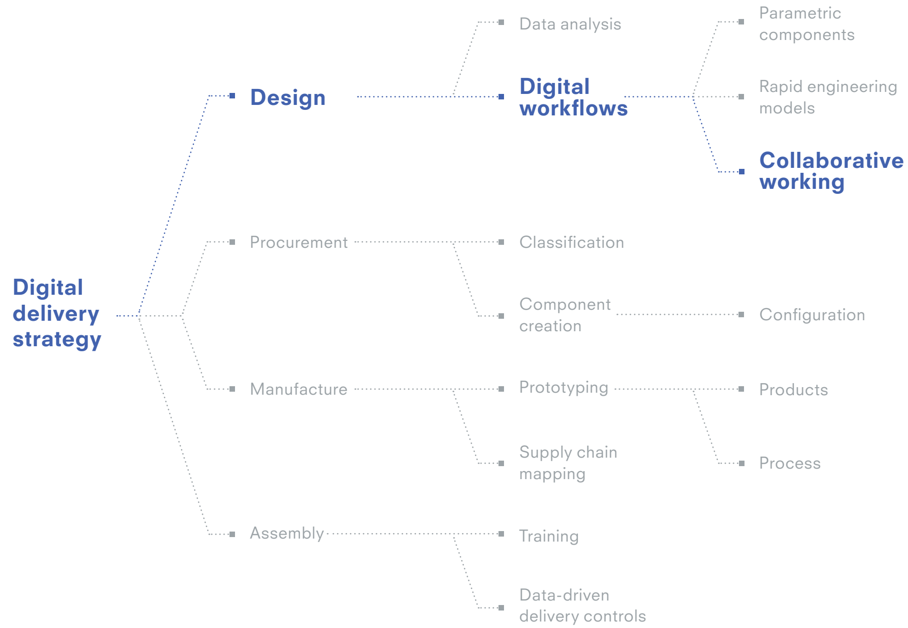
- BIM model (in context of drone survey), including assembly BIM models from HE library;
- Schedule of components;
- GIS data of assembly locations;
- Interactive dashboards of assemblies data, including locations linked to street view geo-photography;
- Fly through of model;
- Model suitable for use in VR.

Typical visualisation of rule sets for an assembly, and an output showing rapid engineering model populated with assemblies





Collaborative working



Collaborative modelling sessions

The rapid engineering model can be used as the basis for collaborative workshops to interrogate and refine the initial proposal.

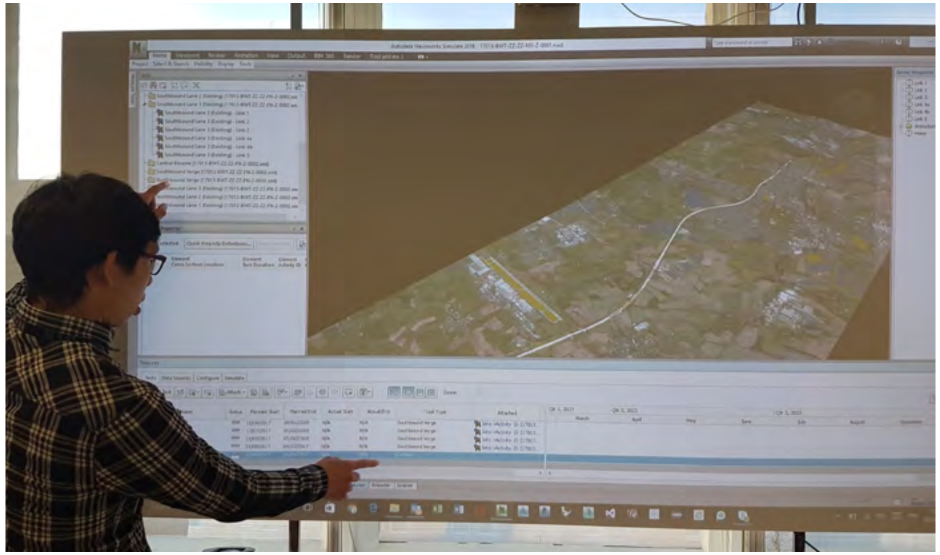
Such is the speed of the digital workflows that is possible to update the model live in response to challenges or inputs from the assembled team. It is therefore essential that the collaborative session includes a sufficiently broad range of views, with experts in specific fields or parts of a project life cycle to be represented (typically design, construction, operation and maintenance).

These sessions can therefore facilitate extremely rapid decision making on the fly, or can generate the need for specific studies which will be taken away from the session and developed in more detail or with a specific set of stakeholders.

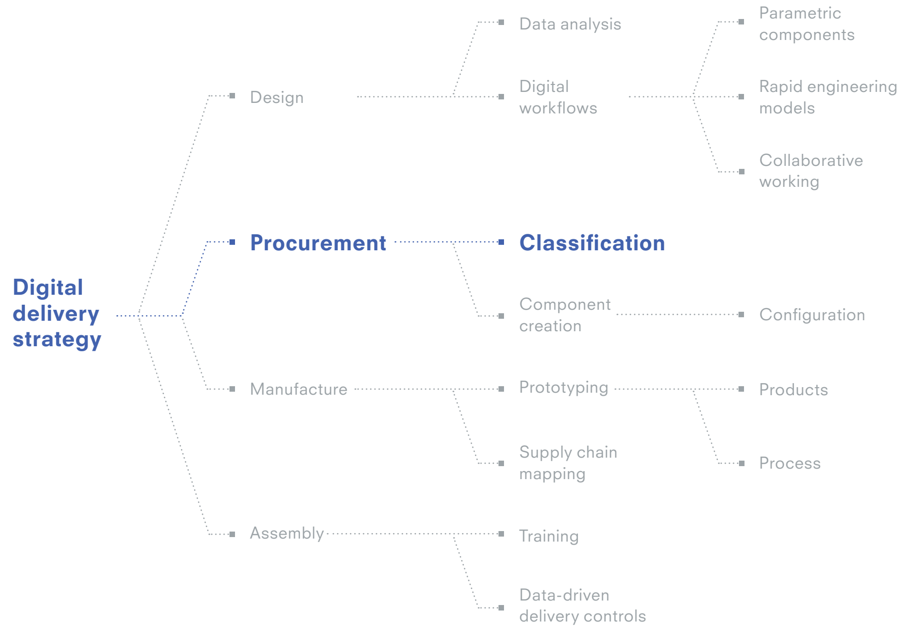
Comments and contributions of all stakeholders tracked and recorded directly onto the model, which as well as being documented can be issued at the end of each session as a record of the design development.

The final model therefore becomes an extremely well articulated brief for the next stage of more detailed design, and captures considerations for every stage of the project life cycle.

Photos from collaborative sessions showing use of models and VR for stakeholder engagement



Classification



Uniclass classification system

One key element of standardisation is the ability to have a common frame of reference for describing buildings, spaces, systems and components.

Uniclass 2015 is a unified classification system for the construction industry, divided into a set of tables which can be used to categorise information for costing, briefing, etc. as well as when preparing specifications or other production documents.

The adoption of Uniclass will be critical for linking the spaces to the physical systems described in earlier systems - Uniclass provides the common thread that can link every scale of the physical elements with the functional and spatial requirements of a facility.

These tables are also suitable for buildings and other assets in use, and maintaining asset management and facilities management information.

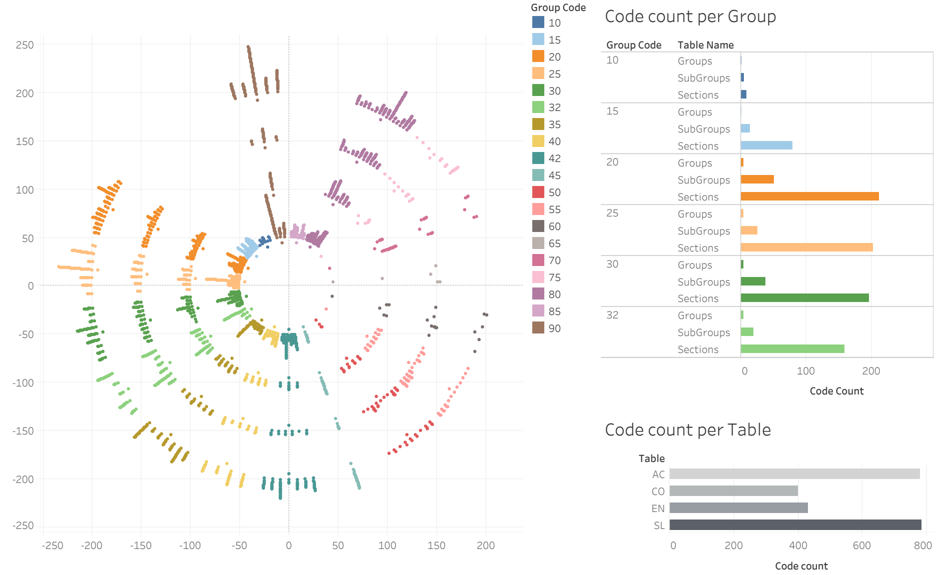
The tables are:

- Ac - Activities
- Co - Complexes
- En - Entities
- SL - Spaces/ locations
- EF - Elements/ functions
- Ss - Systems
- Pr - Products

- CA - Construction aids
- FI - Form of information
- PM - Project management

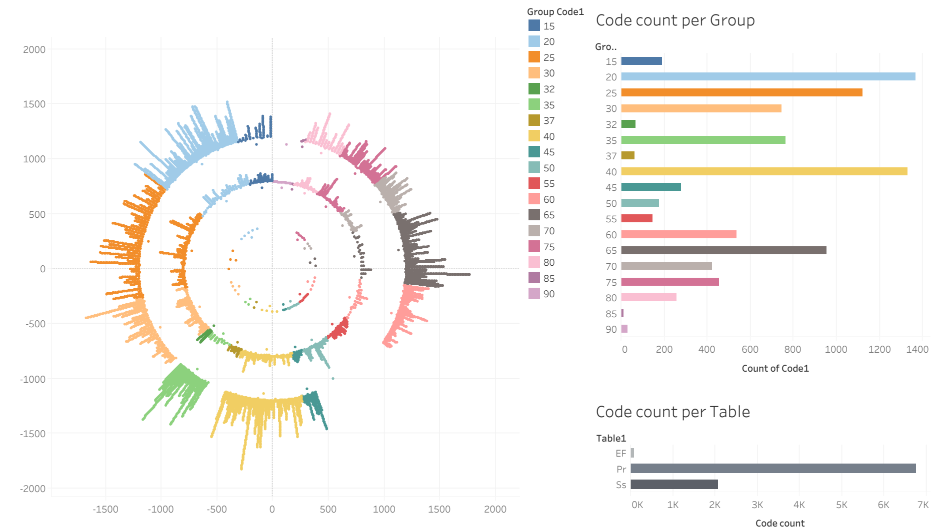
The example on the following pages uses passenger tunnel lining for the Elizabeth Line to show how Uniclass works at a range of scales from an entire facility, down to the individual products.

The last three tables listed above also provide classifications specific to the delivery phase of the project.



Above:
Data visualisation for activities, complexes, entities and spaces tables

Below:
Data visualisation for elements, systems and products tables



Uniclass classification - at Asset level

Ac -	Activities
Ac_80	Transport activities
Ac_80_10	Loading and embarkation activities
Ac_80_10_60	Passenger arriving
Ac_80_10_61	Passenger departing
Ac_80_10_62	Passenger disembarking
Ac_80_10_63	Passenger embarking
Ac_80_10_64	Passenger gathering
Ac_80_10_86	Ticketing
Ac_80_50	Railway activities
Ac_80_50_71	Rail signal controlling
Ac_80_50_73	Railway track buffering
Ac_80_50_75	Railway travel
Ac_80_50_90	Train stopping
Ac_80_60	Rail storage and maintenance activities
Ac_80_60_11	Carriage cleaning
Ac_80_60_26	Engine fuelling
Ac_80_60_27	Engine inspecting
Ac_80_60_28	Engine servicing
Ac_80_60_29	Engine washing
Ac_80_60_70	Rail repairing
Ac_90	Circulation and plant activities
Ac_90_10	Circulation activities
Ac_90_10_16	Covered walking
Ac_90_10_24	Dropping-off and collecting
Ac_90_10_27	Entering and exiting
Ac_90_10_49	Lift stopping and calling
Ac_90_10_50	Lift travelling
Ac_90_10_96	Wheelchair travelling
Ac_90_20	Common activities
Ac_90_20_13	Changing
Ac_90_20_69	Queuing
Ac_90_20_96	Waiting

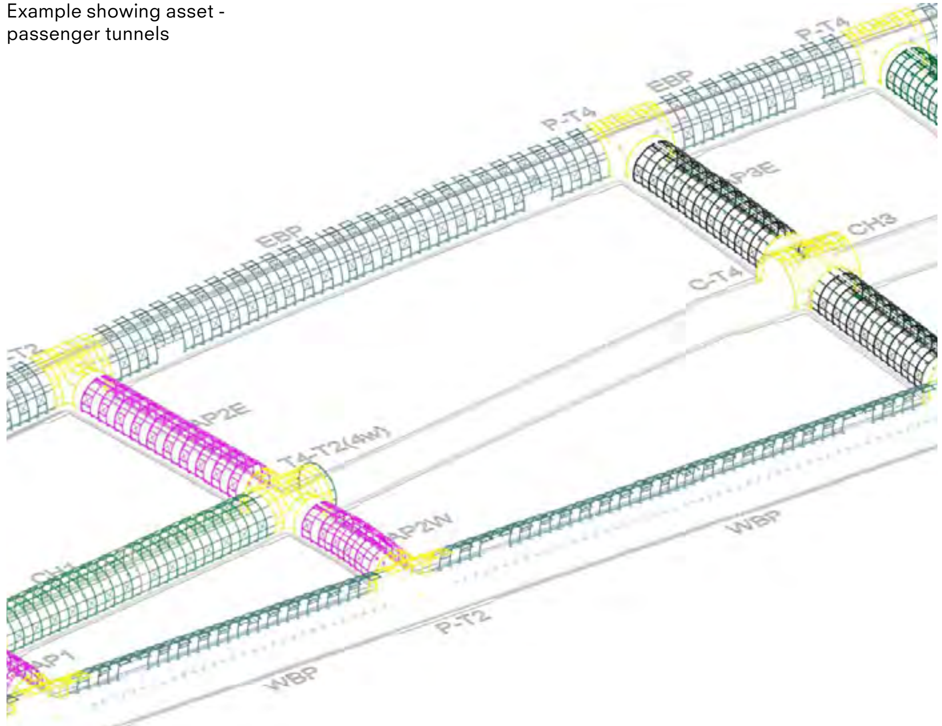
Co	Complexes
Co_80	Transport complexes
Co_80_50	Railway complexes
Co_80_50_37	High-speed rail complexes
Co_80_50_51	Main line rail complexes
Co_80_50_73	Rail network
Co_80_50_74	Railway stations
Co_80_50_93	Underground rail complexes
Co_80_50_94	Underground railway stations

En -	Entities
En_80	Transport entities
En_80_50	Railway entities
En_80_50_74	Railway station buildings
En_80_50_80	Single sided platforms
En_80_90	Transport hub entities
En_80_96	Tunnels and shafts
En_80_96_80	Shafts
En_80_96_90	Tunnels

SL -	Spaces / locations
SL_80	Transport spaces
SL_80_50	Railways
SL_80_50_75	Railway tracks
SL_80_50_77	Railway signal control spaces
SL_80_50_90	Train stops

EF -	Elements / functions
Ss -	Systems
Pr -	Products

Example showing asset - passenger tunnels



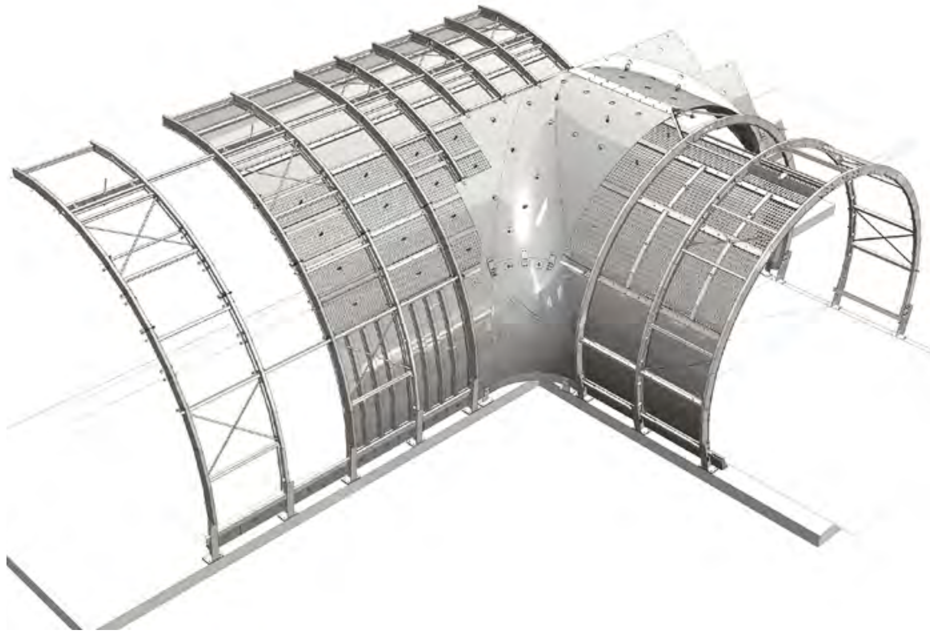
Uniclass classification - at Assembly level

EF -	**Elements / functions**
EF_20	Structural elements
EF_20_10	Frames
EF_25	Wall and barrier elements
EF_25_10	Walls
EF_70	Electrical power and lighting functions
EF_70_30	Electricity distribution and transmission
EF_70_80	Lighting
EF_75	Communications, security, safety and protection functions
EF_75_10	Communication
EF_75_30	Signalling
EF_75_40	Security
EF_75_50	Safety and protection

Ss -	**Systems**
Ss_25	Wall and barrier systems
Ss_25_10	Framed wall systems
Ss_25_10_32	Framed wall structure systems
Ss_25_10_32_45	Light steel wall framing systems
Ss_25_12	Panel wall structure systems
Ss_25_12_15	Concrete panel wall systems
Ss_25_20_33	Glass fibre reinforced concrete (GRC) cladding systems
Ss_25_20_33_35	GRC cladding systems
Ss_25_25	Wall lining systems
Ss_25_25_05	Acoustic panel systems

Pr -	**Products**

Example showing passenger tunnel lining intersection for the Elizabeth Line stations



Uniclass classification - at Sub-assembly level

Ss -	Systems
Ss_25	Wall and barrier systems
Ss_25_10	Framed wall systems
Ss_25_10_32	Framed wall structure systems
Ss_25_10_32_45	Light steel wall framing systems
Ss_25_12	Panel wall structure systems
Ss_25_12_15	Concrete panel wall systems
Ss_25_20_33	Glass fibre reinforced concrete (GRC) cladding systems
Ss_25_20_33_35	GRC cladding systems
Ss_25_25	Wall lining systems
Ss_25_25_05	Acoustic panel systems
Ss_40_10	Signage systems
Ss_40_85_70	Rail FF&E systems
Ss_40_85_70_60	Passenger concourse FF&E systems
Ss_70	Electrical systems
Ss_70_30	Electricity distribution and transmission systems
Ss_70_30_45	Low-voltage systems
Ss_70_30_45_45	Low-voltage distribution systems
Ss_70_30_80	Small power systems
Ss_70_30_80_35	Hard-wired voltage small power systems
Ss_70_30_80_45	Low-voltage small power systems with prefabricated wiring
Ss_70_80	Lighting systems
Ss_70_80_33	General space lighting systems
Ss_70_80_33_33	General lighting systems with prefabricated wiring
Ss_70_80_33_35	Hard-wired general lighting systems
Ss_75	Communications, security, safety, control and protection systems
Ss_75_10	Communications systems
Ss_75_10_21	Data distribution and telecommunications systems
Ss_75_10_21_21	Data distribution systems
Ss_75_10_21_88	Telecommunications systems
Ss_75_10_68	Public communications systems
Ss_75_10_68_02	Advertising display systems
Ss_75_10_68_13	Clock systems
Ss_75_10_68_68	Public address systems
Ss_75_30	Signal systems
Ss_75_30_70	Railway signal and control systems
Ss_75_30_70_70	Rail signal systems
Ss_75_40	Security systems
Ss_75_40_53	Monitoring systems
Ss_75_40_53_86	Surveillance systems
Ss_75_40_73	Security screening systems
Ss_75_50_11	Call and alarm systems
Ss_75_50_11_05	Assistance call systems
Ss_75_50_11_27	Emergency voice communication systems
Ss_75_50_11_95	Voice alarm systems

Pr - **Products**

Example showing passenger tunnel lining ladder frame for the Elizabeth Line stations

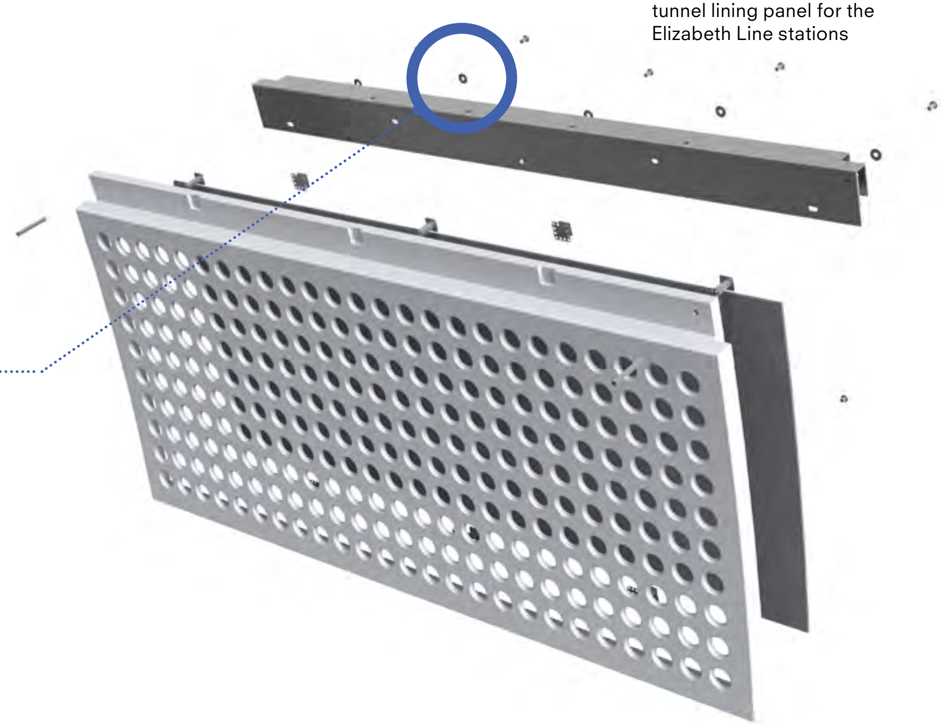
Uniclass classification - at Component level

Pr -	**Products**
Pr_20	Structure and general products
Pr_20_29	Fastener products
Pr_20_29_60	Packings, washers and spacers
Pr_20_29_60_96	Washers

At this level the components can be linked to individual manufacturers' data. This is described in more detail in 'Product Data Definition - A technical specification for defining and sharing structured digital construction product information' (S. Thompson, April 2016).

LEXiCON, hosted by the Construction Products Association (CPA), will implement the methodology set out in the Product Data Definition document and facilitate the capture of the following information relating to products:

- Essential Requirements for the Harmonised European Standards (hENs);
- Requirements from other Standards (e.g. relevant ISO, EN or BS standards other than those captured above);
- Industry recognised documents;
- Mandated requirements for a specific sector or application e.g. NRM for Chartered Surveyors;
- Non-mandated but recognised within a specific sector e.g. CIBSE Guide M;
- Industry agreed and recognised e.g. identified by a professional institute, trade association or cross-industry group;
- User-defined additional terms proposed for approval and wider adoption.



Example showing acoustic tunnel lining panel for the Elizabeth Line stations

Below: Example of approved product data template from 'Product Data Definition' http://bim-level2.org/globalassets/pdfs/product-data-definition_v2.pdf

Template Reference 1234
Classification Pr_20_75_52_16_Carbon steel hot finished hollow sections
Description Hot finished structural hollow sections - example
Template Author Me
Template Status Approved

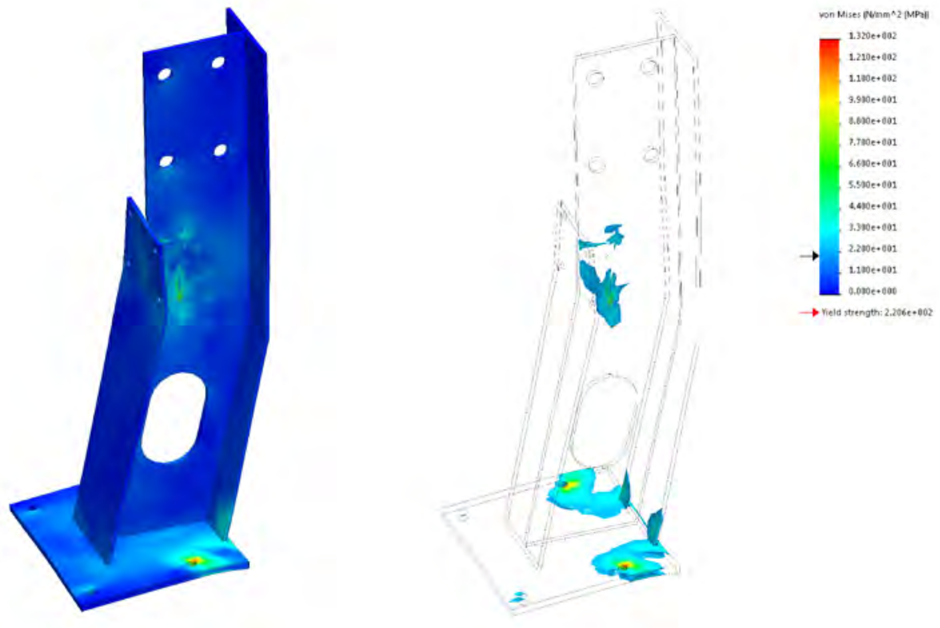
Template Revision 1
Template Revision Date 2016-04-12
Completion Revision 1
Completion Revision Date 2016-04-12
Relevant Authority A N Other

Parameter	Value	Units	Description	Measure	Responsibility	Completed by	Unique identifier	Information Sets
Tolerances		mm	Tolerances on dimensions and shape for hot finished structural hollow sections	Length	Manufacturer		[illegible]	[illegible]
Elongation		%	Elongation in accordance with Tables A.3 and B.3 of BS EN 10210-1: 2006	Ratio	Manufacturer		[illegible]	[illegible]
Tensile strength		N/mm2	Tensile strength in accordance with Tables A.3 and B.3 of BS EN 10210-1: 2006	Force	Manufacturer		[illegible]	[illegible]
Yield strength		N/mm2	Yield strength in accordance with Tables A.3 and B.3 of BS EN 10210-1: 2006	Force	Manufacturer		[illegible]	[illegible]
Impact strength		N/mm2	Impact strength in accordance with Tables A.3 and B.3 of BS EN 10210-1: 2006	Force	Manufacturer		[illegible]	[illegible]
Weldability			CEV value specified, in accordance with Tables A.2 and B.2 of BS EN 10210-1: 2006		Manufacturer		[illegible]	[illegible]
Durability			In accordance with Clause 6.7.2 of BS EN 10210-1: 2006	-	Manufacturer		[illegible]	[illegible]
Outside diameter		mm	Outside diameter D of hollow section	Length	Structural Engineer		[illegible]	[illegible]
External perimeter		mm	External perimeter of square, rectangular or elliptical section	Length	Structural Engineer		[illegible]	[illegible]
Steel grade			Steel name, e.g. S355 NH		Structural Engineer		[illegible]	[illegible]
Cross Sectional Area		cm2	Cross sectional area of the section	Area	Structural Engineer		[illegible]	[illegible]
Thickness		mm	Specified thickness	Length	Structural Engineer		[illegible]	[illegible]
Mass		kg/m	Mass per unit length	Mass	Structural Engineer		[illegible]	[illegible]
Second Moment of Area		cm4	Second Moment of Area	Moment of inertia	Structural Engineer		[illegible]	[illegible]
Radius of Gyration		cm	Radius of Gyration	Length	Structural Engineer		[illegible]	[illegible]
Elastic Section Modulus		cm3	Elastic Section Modulus	Section Modulus	Structural Engineer		[illegible]	[illegible]
Plastic Section Modulus		cm3	Plastic Section Modulus	Section Modulus	Structural Engineer		[illegible]	[illegible]
Torsional Inertia Constant		cm4	Torsional Inertia Constant	Moment of inertia	Structural Engineer		[illegible]	[illegible]
Torsional Modulus Constant		cm3	Torsional Modulus Constant	-	Structural Engineer		[illegible]	[illegible]
Width		mm	Specified side dimension of a square hollow section. Specified dimension of the shorter side of a rectangular hollow section. Specified outside dimension of an elliptical section on its minor axis	Length	Structural Engineer		[illegible]	[illegible]
Height		mm	Specified dimension of the longer side of a rectangular hollow section. Specified outside dimension of an	Length	Structural Engineer		[illegible]	[illegible]

Level of detail below Uniclass

Below Uniclass the level of information relates to the material properties of individual components.

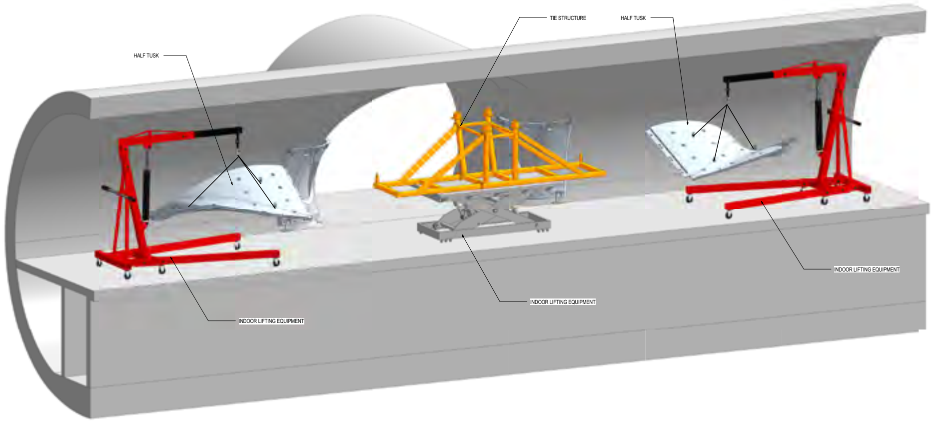
Mechanical properties of individual components - Elizabeth Line tunnel lining ladder frame



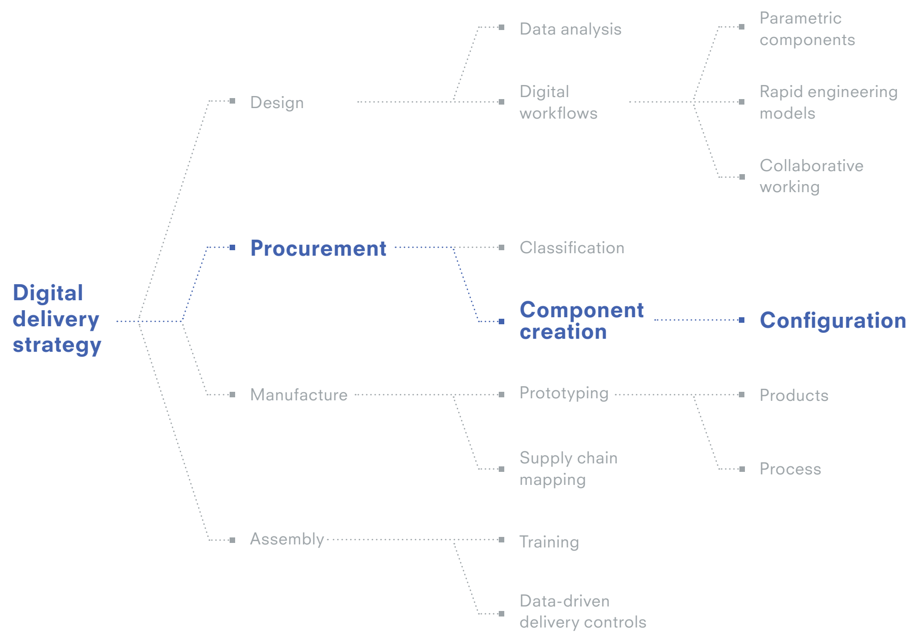
DESIGNATIONS (▼) EN [N°]	AISI/ASTM	DENSITY at 20°C [kg/dm³]	MODULUS OF ELASTICITY at 20°C [GPa]	MEAN COEFFICIENT OF THERMAL EXPANSION [10^{-6}xK^{-1}] 20°C ÷ 200°C	20°C ÷ 400°C	THERMAL CONDUCTIVITY at 20°C [W/(mxK)]	SPECIFIC HEAT at 20°C [J/(kgxK)]	ELECTRICAL RESISTIVITY at 20°C [(Ωxmm²)/m]
1.4372 [I]	201	7,8	200	15,7 [a]	17,5 [b]	15	500 [e]	0,70
1.4373 [I]	202	7,8	200	17,5 [f]	18,4 [b]	15	503 [d]	0,70
1.4371 [I]		7,8	200	17,5	18,5	15	500	0,70
1.4597 [I]		7,8	200	16,5	17,0	15	500	0,73
1.4369 [I]		7,9	190	17,0	18,5	15	500	0,70
1.4310 [I]	301	7,9	200	17,0	18,0	15	500	0,73
1.4319 [I]		7,9	200	16,5	17,5	15	500	0,73
1.4318 [I]	301LN (301L)	7,9	200	16,5	17,5	15	500	0,73
	302 [h]	8,06	193	17,2 [a]	17,8 [b]	16,3 [c]	503	0,72
1.4305 [I]	303	7,9	200	16,5	17,5	15	500	0,73
1.4301 [I]	304	7,9	200	16,5	17,5	15	500	0,73
1.4311 [I]	304LN	7,9	200	16,5	17,5	15	500	0,73
1.4948 [IV]	304H	7,9	200	16,9	17,8	17	450	0,71
1.4307 [I]	304L	7,9	200	16,5	18,0	15	500	0,73

Uniclass classification - in Delivery phase

Ss -	**Systems**
Ss_15_95	Temporary works systems
Ss_15_95_15	Temporary preparatory works systems
Ss_15_95_35	Temporary fixed access, tunnel, shaft, vessel and tower works systems
Ss_15_95_40	Temporary signage and fittings, furnishings and equipment (FF&E) works systems
CA -	**Construction aids**
CA_20_10_20	Mobile working towers
CA_20_30_30	Guardrails
CA_20_30_30_35	Guardboards
CA_20_30_30_36	Handrails
CA_20_30_30_41	Intermediate guardrails
CA_20_30_30_89	Toe boards
CA_20_30_80	Work platforms
CA_20_30_80_01	Adjustable platforms



Component creation + configuration



Component design

Work on a range of projects in the rail, highways and water infrastructure projects show that a component based approach, with the digital components providing a highly representative digital twin of their physical selves, can unlock all of the potential benefits of a DfMA approach.

The benefits case for a DfMA approach was set out in the document 'Delivery Platforms for Government Assets - Creating a Marketplace for Manufactured Spaces' and will not be duplicated here.

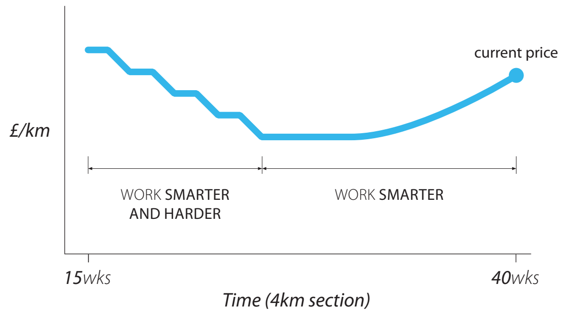
However, the component design should have a low barrier to entry to existing supply chains i.e. manufacturing the components should work with existing skills, processes and tools.

DfMA components should therefore ideally possess the following characteristics:

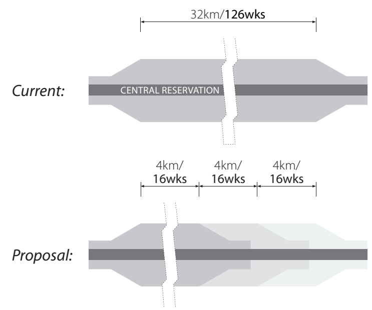
- Highly repeatable and can be manufactured at scale by a wide supply chain;
- Require no specialist skills or equipment that is not widely available;
- Can be manufactured, assembled and pre-tested using rigorous quality assurance to maintain consistency across the programme (in construction and into operation);
- Could be manufactured and assembled using local, semi-skilled labour (following standard training in relevant tasks) to facilitate the creation of apprenticeships and expansion of manufacturing skill set;
- Require minimum materials handling and processing (which inevitable introduces waste and non-value adding activity);
- Use materials that are widely available in the UK;
- Could be developed with MTC to optimise manufacturing processes (including adoption of some level automation if appropriate and desirable).

A proof of concept study carried out for Highways England in 2014 showed that a component based solution to central reservation works would yield the benefits shown here.

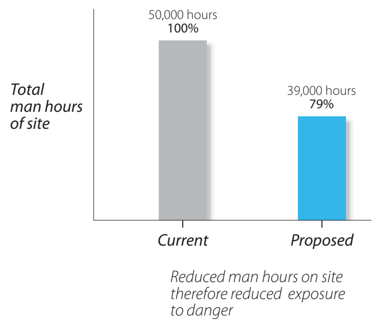
Cost benefit



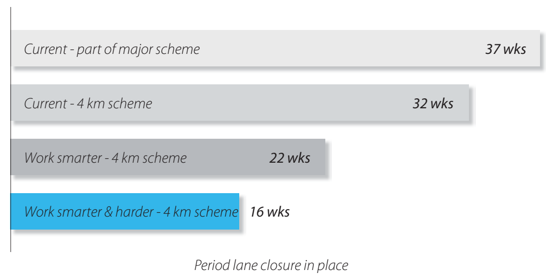
Road user experience



Safety



Programme



Simplifying what we buy and how we buy it

We need to move away from bespoke design and construction and move to standardised, highly productive manufactured solutions.

This can be delivered through a 3 step process:

1. Design and procure in an hour;
2. Manufacture and assemble in days;
3. Benchmark portfolio performance over years.

Step 1 - Design + procure in an hour

Digital configurator

A digital configurator is a database of standard components and elements, with customisable options specific to the building type.

For example: Ikea use a similar tool for their kitchens with a range of user-customisable options (worktops, appliances, doors, handles) based on standard mass-manufactured carcasses that are scalable to suit kitchen size and layout.

BMW allow prospective customers to specify a number of options - colours, trim, engine options etc. - based on a range of standard model chassis.

The intelligent algorithm within the configurator will offer the relevant options consistent with the building type.

For example, choosing ‘school’ will limit the room, types - the spaces - to those relevant to a school.

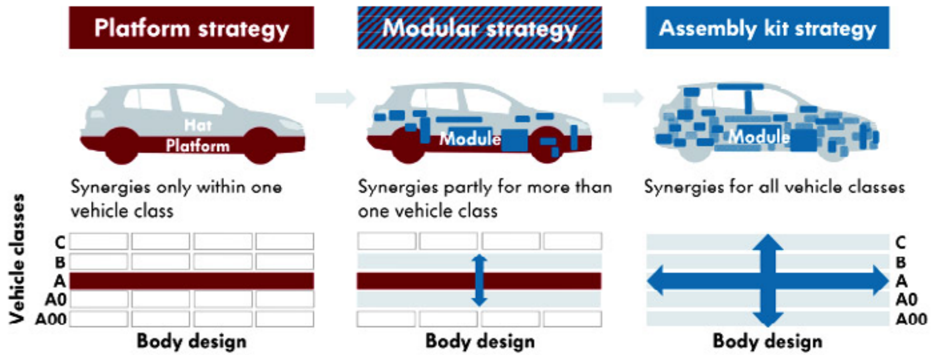
The boundary wall, window and door options for a school classroom differ from those for a High Security prison.

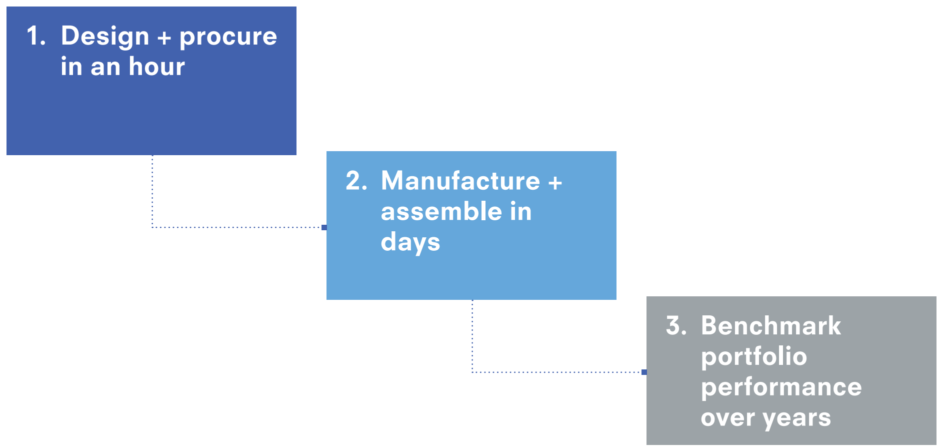
The algorithm will allow the building to be configured based on the size (number of pupils, patients, workers, prisoners etc.) and the footprint (linear, T-shaped etc.), and will include ancillary facilities (staff rooms, canteens etc.) relevant to the building type.

cont’d

VW group’s platform sharing architecture.

Source: DS Raikkonen http://www.f1technical.net/forum/viewtopic.php?t=12881





Virtual marketplace

The virtual marketplace is the key customer interface in which the digital configurator sits.

The digital configurator is embedded in a virtual marketplace and from the algorithm can produce the basic design pre-options, together with a nominal 'Base Price'.

Within the marketplace, the client can add their options. They can choose the external cladding type based on a number of architectural options, the floor and wall finishes etc. All of these options, much like a BMW configurator - will show how they add to the Base Price.

When configuration is complete, the client can 'add to basket' and then shop for more, or proceed to Check Out.

Check out

Checking out launches the procurement process. At this stage, the client knows his 'should cost' for his scheme with options. How the market can and will supply this depends on their operational model.

At a simple level, the options could range from 'Manufacture and Assemble', to 'Finance, Manufacture, Assemble and Operate'.

The market place - of approved suppliers and products - then offers to provide the service requested.

The agreed supplier then moves to Step 2.

Step 2 - Manufacture and assemble in days

With the scope agreed, the procurement route chosen and the supplier selected, the digital configurator will electronically generate the component lists which will be fed to the factory facilities for production.

In parallel, traditional site preparation can commence - earthworks, foundations etc., so the site is ready to receive the components.

In addition to the manufactured components, connections, building services etc., required for the structure, the configurator can generate the plant and equipment needed for assembly and temporary site logistics - messing, offices etc. - again drawn from standard, re-usable units appropriate to the location and scale of the facility.

Step 3 - Benchmark portfolio performance over years

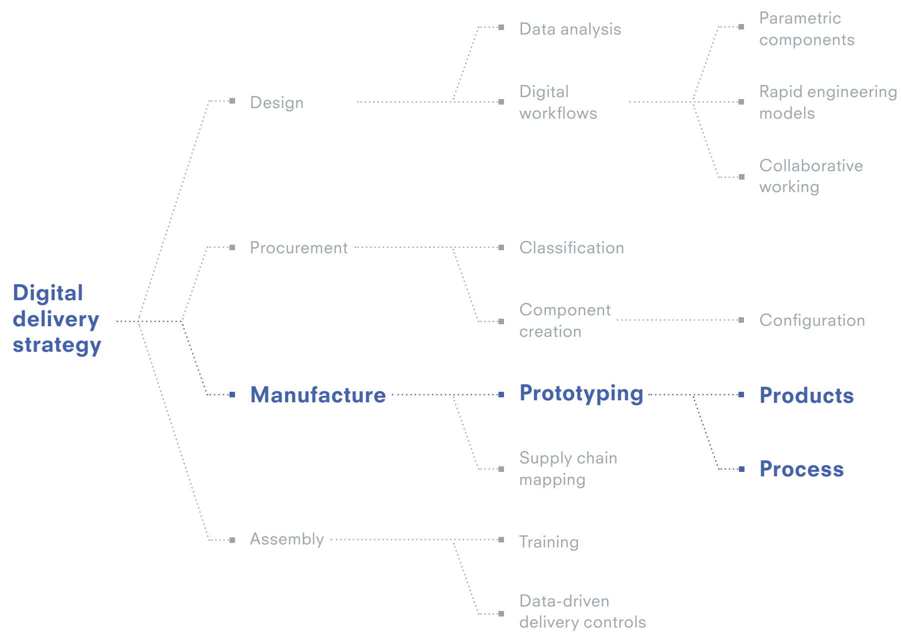
Data will be collected from in service performance to ensure outputs and outcomes are delivered across the estate.

Data can inform strategic interventions for maintenance and operational effectiveness and be used to ensure appropriate strategic spares are held to service the needs of the estate.

Output from the data and benchmarking will be used to refine and optimise the designs and methodologies and to inform decisions taken at the front end of new projects.

cont'd

Prototyping



Prototyping

Analysis and experience to date suggest that many major programmes could be delivered using a limited number of relatively simple components, developed in such a way that they can be procured at low cost but consistent quality from a wide supply chain.

Once the repeatable elements have been identified and described, the BIM library objects can be used collaboratively by the project team to establish an installation sequence that is much more like factory assembly than traditional construction, creating the potential for:

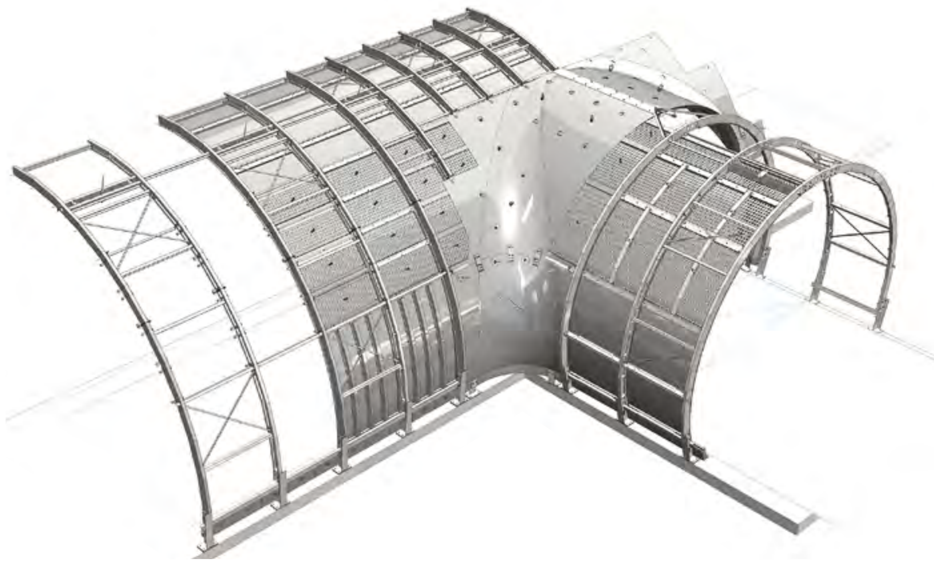
- Standardising working;
- Capturing and incrementally improving upon of best in class methodologies;
- Using a non-traditional workforce specifically trained in installing the proposed solution.

For certain critical and highly repeated elements the benefits of refining and perfecting them are enormous; any improvements that are made as a result of this process will be multiplied across the programme. Any issues that arise through failure to prototype will conversely appear numerous times.

In the development of industrialised products, the purpose of a prototype is:

- Testing and trialling a new design;
- Testing and optimising installation or construction sequences;
- Identifying any opportunities to refine and improve the proposed design, installation etc. before commencing large scale manufacture.

cont'd



Virtual + physical prototypes for Elizabeth Line passenger tunnel lining

Prototyping cont'd

The ultimate aim is risk reduction, by learning as much as possible from the prototype in a controlled environment, off the project critical path, to inform the development of the production run of the system or element.

There are varying degrees of prototype, which provide differing levels of feedback and learning but have commensurate levels of time and cost associated with them, including:

- Digital (virtual) prototypes;
- Physical prototypes.

Virtual prototypes

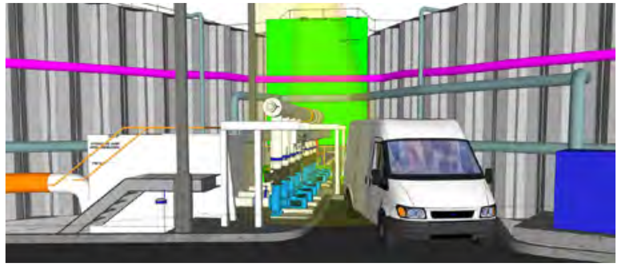
These are developed in sophisticated software packages that allow a wide range of analysis to be carried out without ever producing a physical element. Product design software allows the digital components to have 'real' properties such as density to allow analysis including:

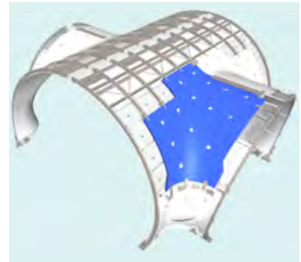
- Mass and centre of gravity (for e.g. craneage studies);
- Failure modes and effects analysis (FMEA);
- Computational fluid dynamics.

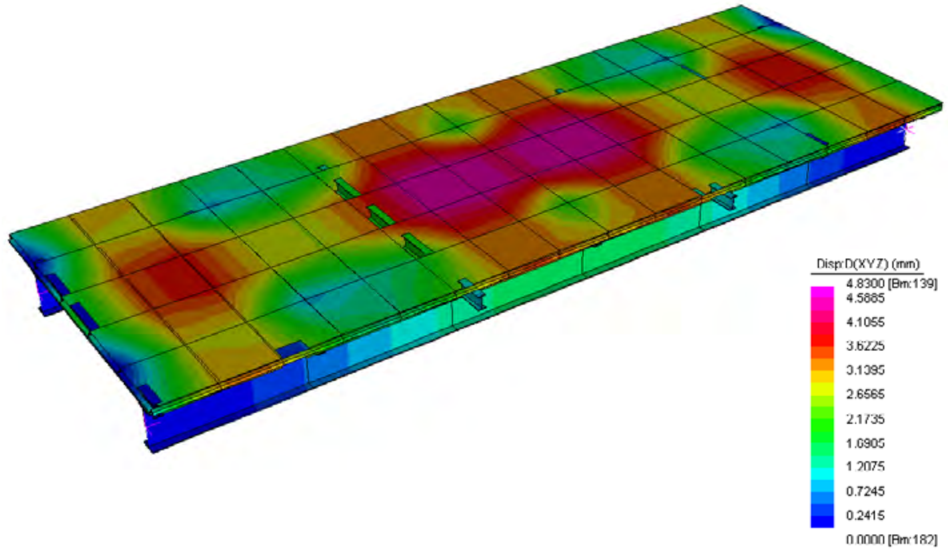
The result is an holistic virtual build that can be iteratively used to refine the solution by:

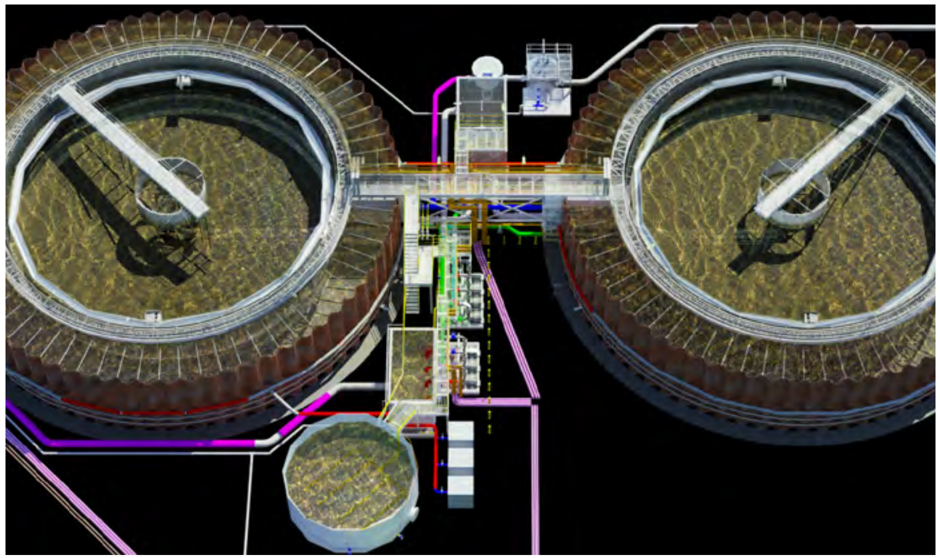
- Developing a model of a sample section of the initial industrial design concept;
- Developing the model to include construction sequence, program, supply chain and resulting cost modelling;
- Filtering the model to determine quantities, program, site labour histograms etc.;
- Assessing the outcomes of the virtual build against local benchmark norms for cost and against aesthetic and quality issues;
- Considering modifications to the components on the component deployment and assembly techniques in response.

cont'd









Prototyping cont'd

Physical prototype

This is a full or partial section of an element or assembly, usually at full scale and using the final proposed materials. A prototype can be used to test the physical characteristics of an element or system, including installation. Prototypes are typically created for learning purposes only, not for deploying in a live environment. Significant issues may be identified in the creation of a prototype.

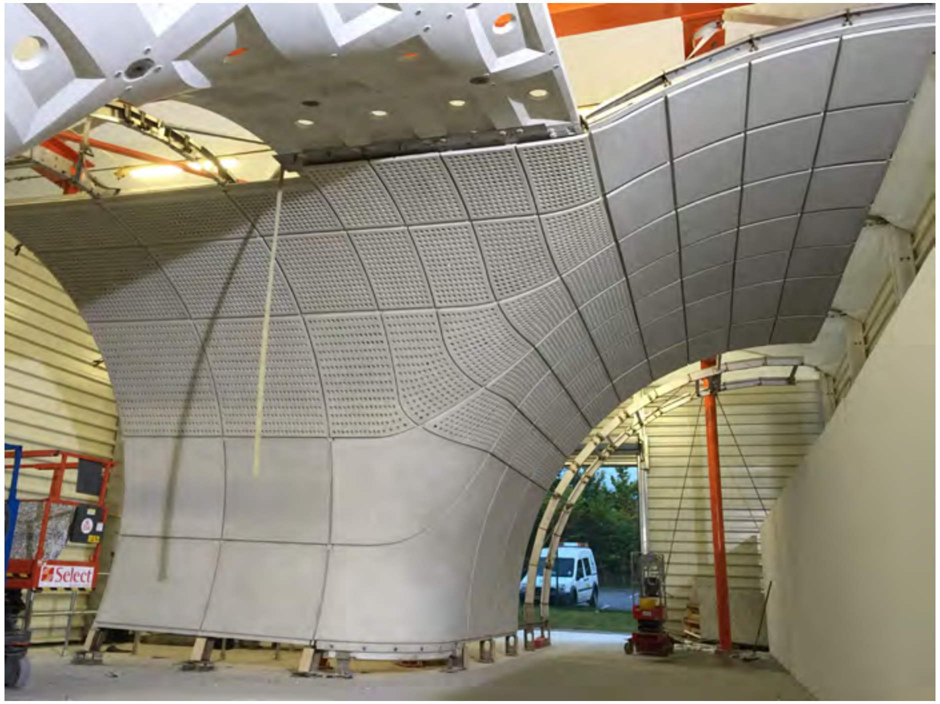
The benefits of creating physical prototypes are particularly high for the transformation roll-out project - before embarking on a process of building 8,000 prisoner spaces, a relatively small prototype could be used to:

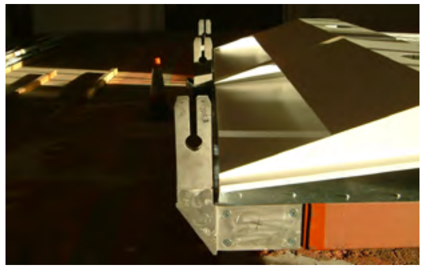
- Demonstrate the delivery system in practice;
- Optimise the assembly sequence and create installation / health + safety guides;
- Provide detailed data regarding assembly to inform construction programmes, logistics planning etc. with a relatively high degree of certainty (compared to current efforts which are necessarily based on assumptions);
- Provide training for assembly crews, crane operatives etc.

The benefits will include:

- Better, more targeted engagement of suppliers as the required end product will be extremely well understood and defined;
- More objective assessment of suppliers as the quality of their products can be measured against a known standard;
- Greater consistency across the two buildings - labour teams will be able to work on any plot as the methods of construction will be identical;
- Assembly teams can be trained using the prototype before going on site, so productivity on site will be high from day 1 (no learning curve on actual buildings)
- Greater opportunity for measuring progress on site, creating feedback loops and driving continual improvement.

Physical prototypes developed for a number of projects + sectors





Process prototyping

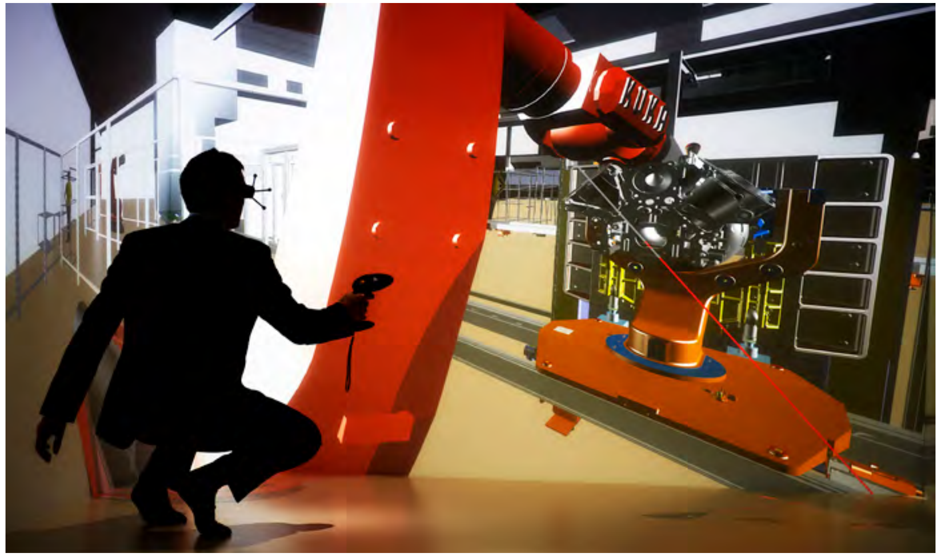
Process prototypes are well established in other industries such as aerospace, manufacturing or defence. Those sectors rely on virtual prototypes to verify and validate processes prior the physical commission of the equipment. The virtual process prototype allows:

- Rapid testing of different manufacturing sequences under a full scale production scenario;
- Optimum utilisation of resources, material and equipment;
- Elimination of physical collisions with structure;
- Identification and mitigation of potential process capability issues (i.e. time, cost and quality);
- Reduction of installation and commissioning time;
- Validation of robotic paths and programmable logic controller programs;
- Identification and mitigation of ergonomic and health and safety issues;
- Quicker natural interpretation for better informed decisions;
- Replacement of expensive full scale prototypes;
- Operator training;
- Optimization of design for manufacture and assembly (Design for 'x');
- Bespoke tooling, jigs and fixtures can be identified.

Companies in those industries have benefited from using virtual prototypes to optimise their manufacturing processes before the physical installation and achieving, in some cases, significant figures:

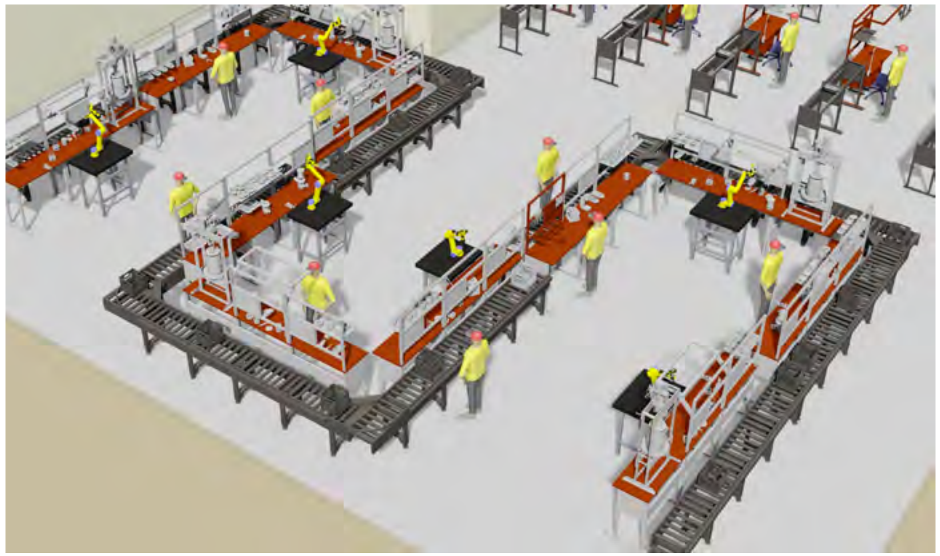
- Reduction of 25% on annual operational costs;
- Reduction of 80% on capital equipment;
- Increase utilisation of resources by 20%;
- De-risked strategy through simulation techniques;
- Part count reduced by 30%;
- Assembly cycle time reduced by 27%;
- Variable volume and product assembly process;
- Reduced facility commissioning time.

cont'd



Virtual prototype within the immersive CAVE (Cave Automatic Virtual Environment) at The Manufacturing Technology Centre (MTC) in Coventry

Production line virtual prototype (courtesy of The Manufacturing Technology Centre)



Process prototyping cont'd

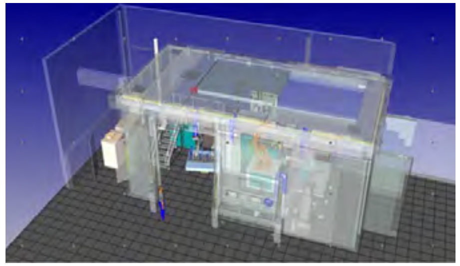
Companies also run pilot processes after the virtual prototype validation in order to test and trial, within a controlled production environment, the future manufacturing process. This enables companies to:

- Identify potential capability issues and mitigate them prior to escalating to full production;
- Test and debug different line configurations or set ups without having to disrupt other production areas;
- Optimise the manufacturing line prior to full scale-production.

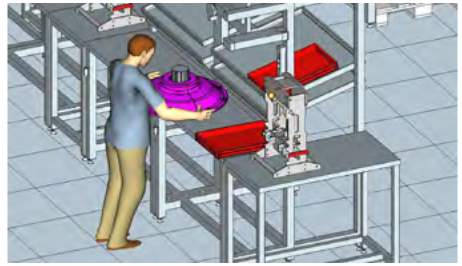
Virtual prototype testing production line configuration

View inside the MTC CAVE

All images on this page courtesy of The Manufacturing Technology Centre

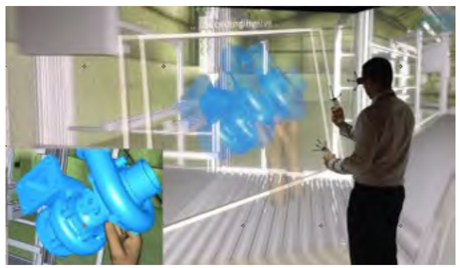


Virtual prototype of a laser welding cell

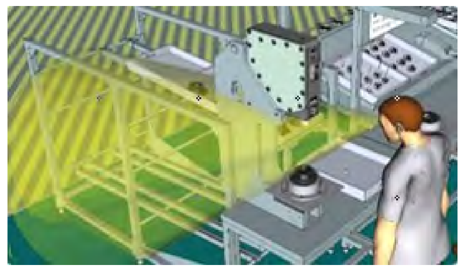


Process simulation

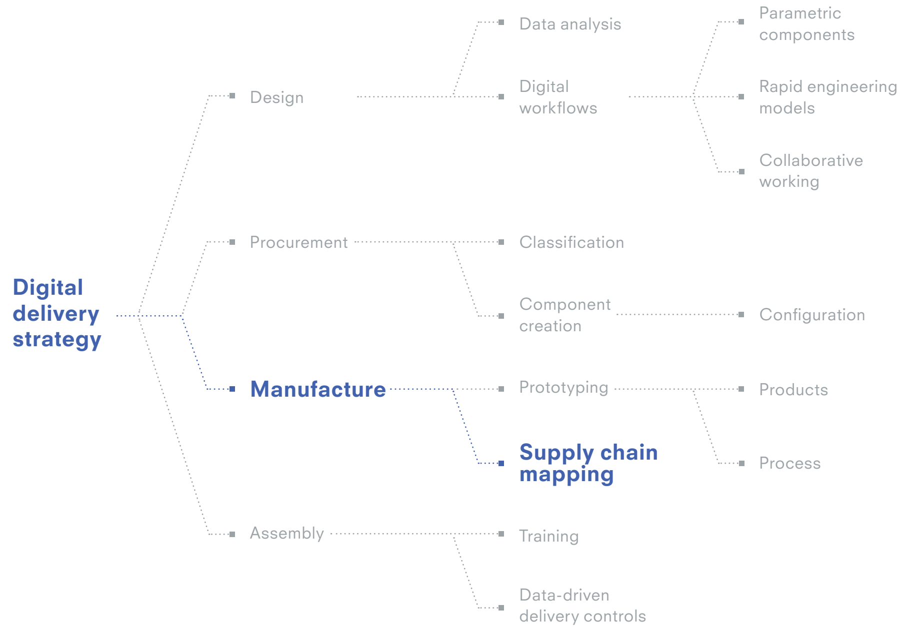
Assessment of worker's visibility using a virtual prototype



Engineering review of a component using Virtual Reality



Supply chain mapping



Supply chain mapping

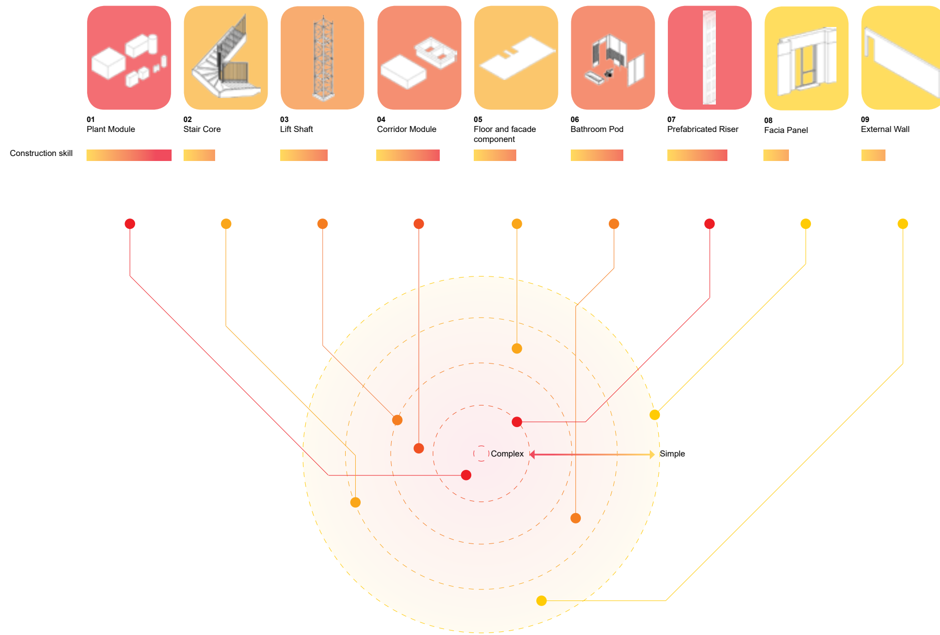
The use of an industrialised approach allows the supply chain to be treated very differently than in traditional construction. For instance, manufactured products are often made many thousands of miles away from their point of use; value is created where operatives are low cost and abundant. This is further enhanced by ensuring that manufactured products can be assembled by low skilled personnel, making the supply chain as wide (and therefore as competitive) as possible; this may extend to non-construction companies.

The diagrams on the right are a typical output of an assessment of the components required to create a roll out programme. This assessment could be developed specifically for the transformation project at the next stage (as part of the standardisation and optimisation exercise).

In particular, the ability to develop components using low skilled labour could facilitate the use of prisoner population manufacturing capability, or e.g. using the workforce in Scotland who traditionally work in the oil + gas sector.

Once the design analysis is complete, it will be necessary to start identifying supply chain partners for the delivery of the scheme. This assessment may be far-ranging and will consider components in terms of:

- Size;
- Weight;
- Complexity.



Component assessment - potential for using low skilled operatives

cont'd

Supply chain mapping cont’d

The design of the repeatable elements can then be refined in line with supply chain capability and capacity. By working with and designing ‘towards’ a supply chain the benefits of their existing skills can be optimised, with benefits to cost and quality.

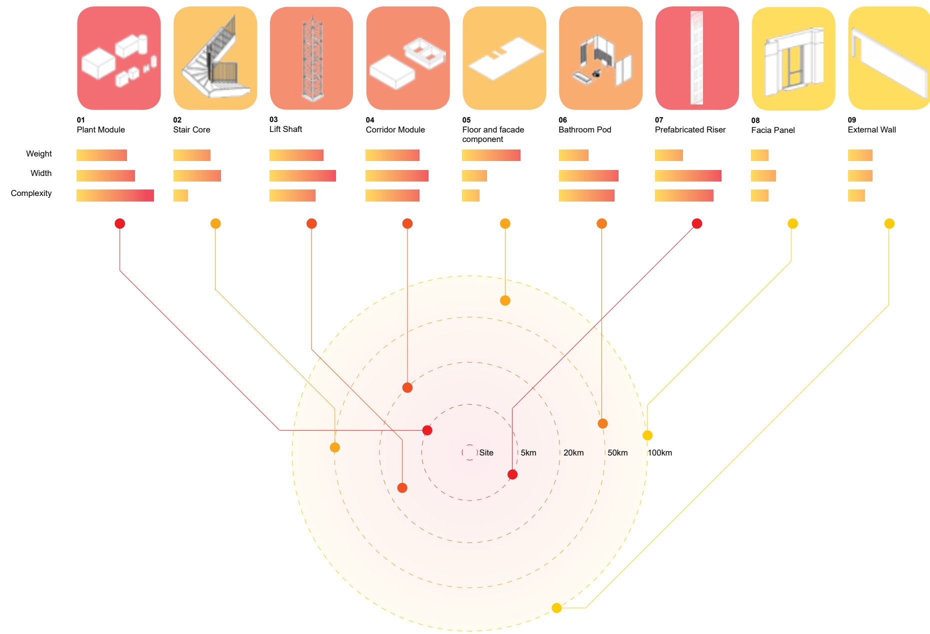
Outcomes should include:

- Extremely wide, and therefore resilient, supply chain for all major components with good regional coverage for all sites (e.g. value mapping shows percentage of overall value to be delivered within known km radius of sites) to maintain commercial advantage while minimising transport and logistics costs;
- Ability to utilise a number of small companies rather than rely on large, ‘single source’ suppliers;
- Ability to manufacture complex components where specialised skills exist, but use local labour for final ‘on site’ assembly.

By working with, where appropriate, supply chain partners the components can be developed to a ‘fit-for-fabrication or manufacture’ stage.

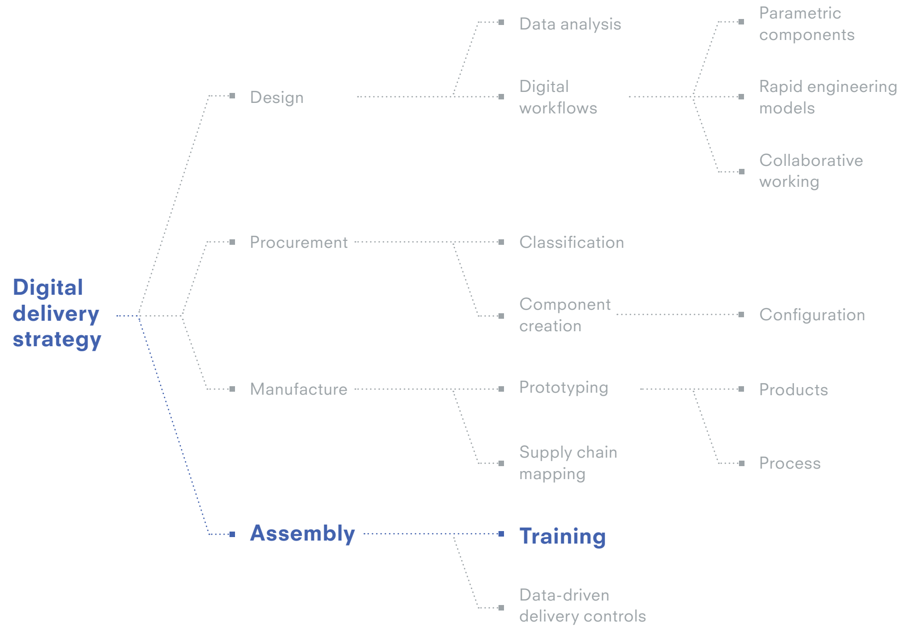
With input from the MTC to drive enhanced manufacture processes, benefits could include:

- Trade contractor drawings virtually eliminated - where possible all coordination takes place using aggregated models;
- Clashes are detected and resolved within the digital environment well before fabrication commences;
- All interfaces fully resolved digitally;
- Fabrication models are used for the ‘virtual building’ exercises described later in this document;
- Impacts of proposed changes assessed using updated models to provide clearly understood and objective metrics;
- ‘As built’ models readily assembled from the fabrication models;
- The aggregated models are ready to be populated with O+M / FM data.



Component assessment - potential for creating value remotely from site

Training


Digital delivery strategy
Design
Data analysis
Digital workflows
Parametric components
Rapid engineering models
Collaborative working
Procurement
Classification
Component creation
Configuration
Manufacture
Prototyping
Products
Process
Supply chain mapping
Assembly
Training
Data-driven delivery controls

Skills scenarios

Adopting DfMA strategy will necessitate a significant growth in manufacturing skills, requiring new apprenticeships and training regimes.

The matrix on the right references the characteristics that were described earlier, showing the skills requirements for each.

While componentised and volumetric solutions require a hybrid of traditional and off-site skills, a manufactured solution will require factory-based and assembly skills, plus better logistics planning etc.

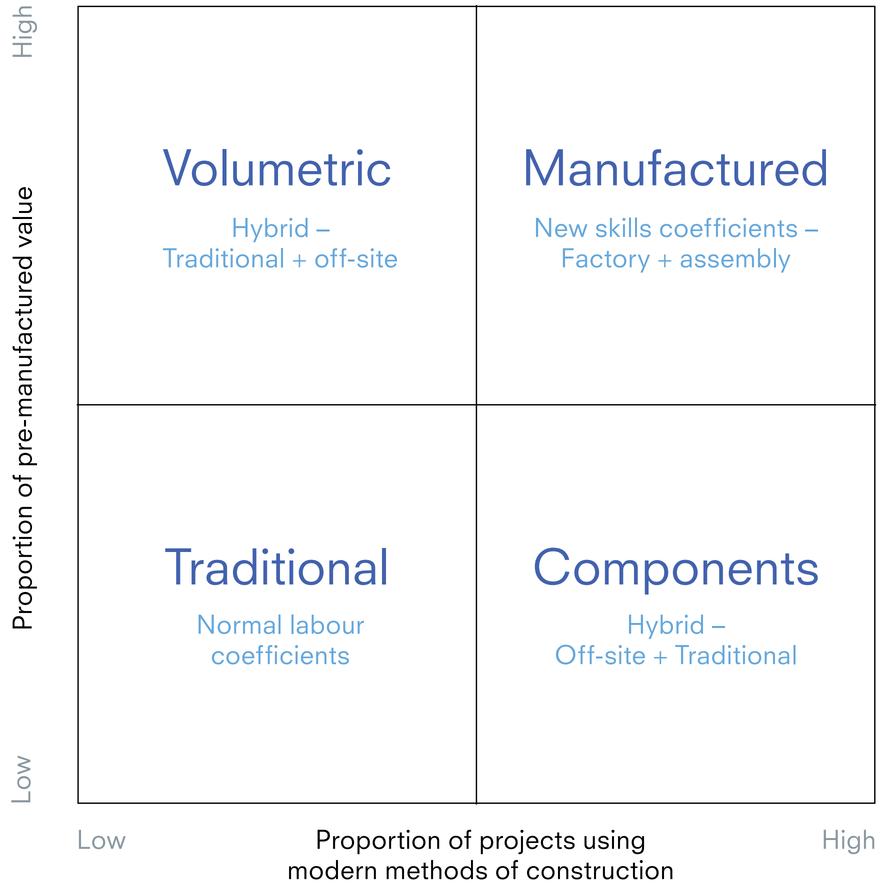
This could be further enhanced by ensuring that manufactured products can be assembled by low skilled personnel.

This could certainly facilitate the use of apprentices as described in HM Treasury's report 'Fixing the Foundations'.

This approach could also make use of lower skilled, local labour on individual site, to carry out standardised tasks alongside more skilled operatives.

Large scale infrastructure programmes offer the potential for using existing or enhanced manufacturing capability; delivery systems could be designed to use simple but highly repeated components that could be made by very low skilled operatives.

Some of the methodologies for delivering digitally enabled compnent-based solutions are considered on the pages that follow.

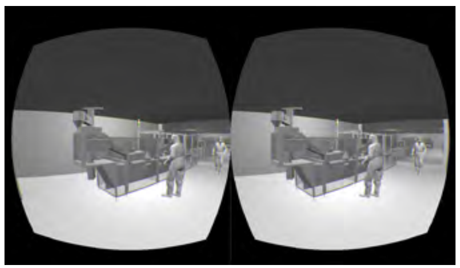


Advanced construction training

Another step in ensuring high productivity and safety on site is using all of the technology that is available for the training of operatives. Virtual prototypes can be used to train operatives in the assembly of components, sub-assemblies and entire projects in a very safe and low-cost environment before they are allowed to enter the relatively higher-risk live environment of a site. Installation sequences can be tested and optimised so that time on site is not spent working out problems.

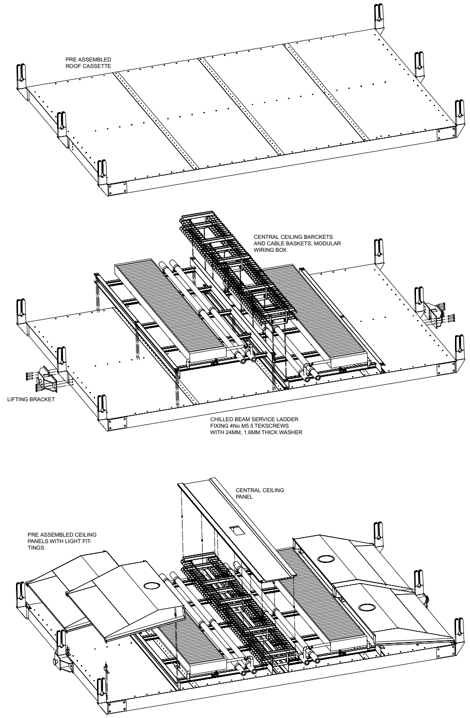
There are a range of tools and outputs to do this, including:

- 'Ikea' style diagrams;
- Animations;
- Training guides;
- Immersive / virtual reality training programmes;
- Daily 'tool box talks' using the BIM models ahead of a work shift on site to talk operatives through the work ahead, point out particular health and safety issues and ensure everyone is clear on the tasks;
- Visual method statements accessed via QR codes attached to the physical components at point of work.

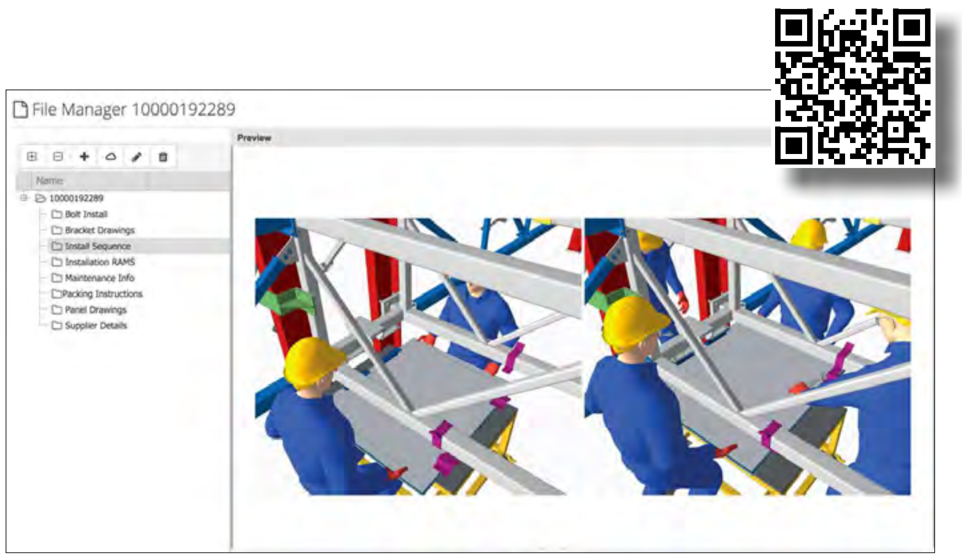


Oculus Rift goggles used for virtual induction

cont'd



Extract from an assembly guide



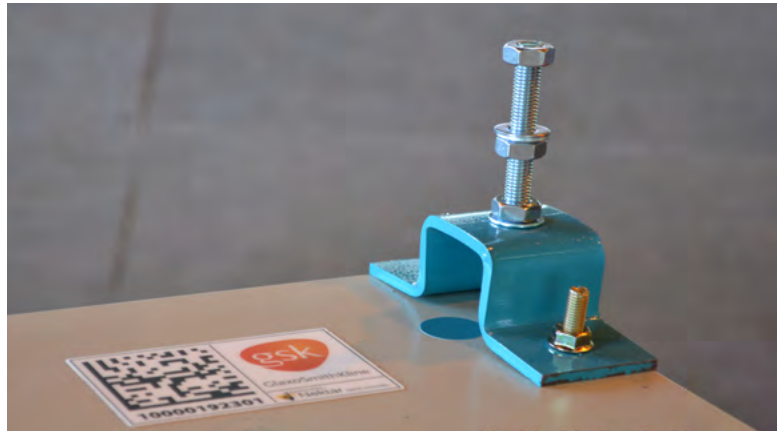
As well as increasing the productivity of operatives, these methods offer the possibility of using low skilled operatives to deliver high quality buildings.

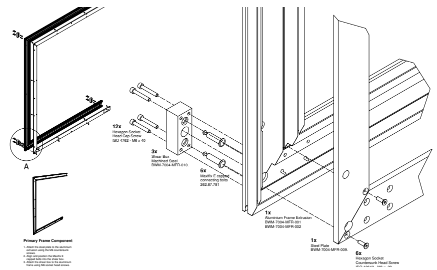
Bryden Wood has many years of experience in using unskilled labour to create quite complex projects. For the Heathrow and Gatwick Pier segregation modules the initial projects were assembled using traditional site based personnel, relocated to a factory. However, as the installation sequences became optimised and better documented, we were able to take unemployed people with no previous experience and train them to assemble these modules. The result for the client was a labour cost that was reduced by 75%.

For the GlaxoSmithKline (GSK) 'Factory in a Box' Bryden Wood has have successfully used non-construction operatives (ex-Army servicemen) to deliver the project. During the assembly process 17% of the operational hours were expended on briefing, training etc. but the project was delivered with a 60% programme saving and a 75% reduction in workforce.

These training programmes can be extended beyond construction operatives (how to build a facility) to staff (how to work in and operate the facility). For example, for GSK Bryden Wood has developed a virtual induction – operatives 'walk' through the model, select appropriate personal protective equipment (PPE) and answer questions on safety before they can enter their 'work area'.

By ensuring that the correct information is available directly when required, there will be significant benefits in terms of operative safety and productivity.



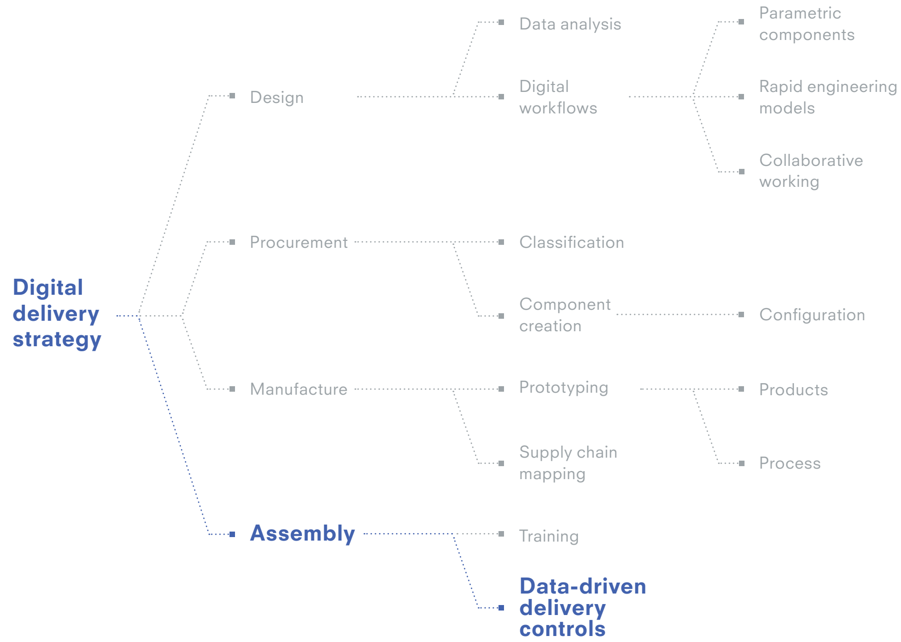


Top: Component colour coding and QR coding for GSK 'Factory in a Box'

Middle: Screen shot from training video

Right: Structural system - training manual

Data-driven delivery controls



Data driven quality checking

The use of point cloud surveys allows pre-coordination checks to be carried out between the as built context and elements that have yet to be installed.

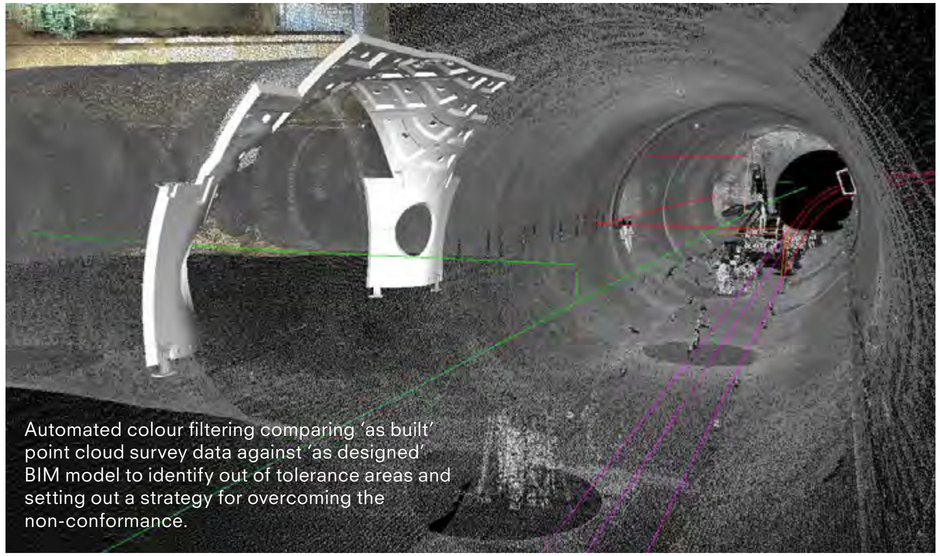
For the tunnel lining to the Elizabeth Line stations automated analysis was developed whereby point cloud surveys from completed sections of the tunnel were combined with and compared to the as designed model for compliance validation.

The variance between the two models is colour filtered as shown in the images on the right, showing areas where:

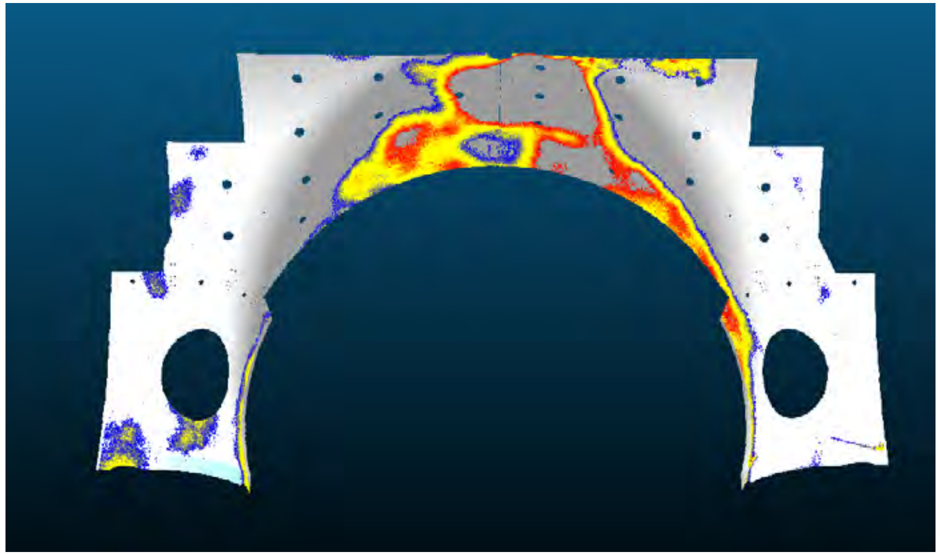
- The as built tunnel is within acceptable tolerance;
- The tunnel is out of tolerance, but this can be accommodated by minor, local adjustments to the components;
- Where the out of tolerance is unacceptable and will require local adjustment to the tunnel (scabbling back).

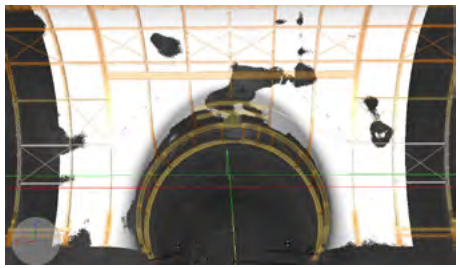
Outcomes and benefits include:

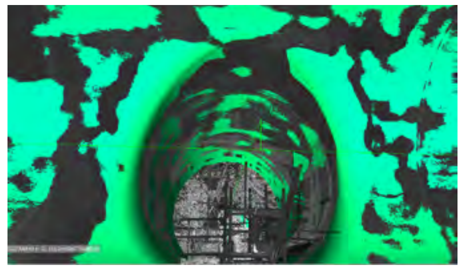
- Issues such as out-of-tolerance or non-compliant installation identified and documented as construction progresses;
- Pro-active management and control of issues identified rather than site operatives unilaterally deciding on a course of action (e.g. forcing elements to fit, or locally modifying elements without proper management / design / documentation and understanding knock on effects);
- Precise coordination of elements that are still in design stage with the actual as built context in which they will be installed;
- Ability to mass customise off site fabricated elements to a suit as-built structure (for precise installation);
- Reduced delays (and knock on effects of teams being unable to progress) leading to greater programme certainty;
- Reduced rework;
- Increased productivity;
- Better documentation of as-built asset for future maintenance, refurbishment or re-purposing;
- Ability to adopt DfMA in a wide range of contexts that might otherwise be prohibitively complicated.



Automated colour filtering comparing 'as built' point cloud survey data against 'as designed' BIM model to identify out of tolerance areas and setting out a strategy for overcoming the non-conformance.



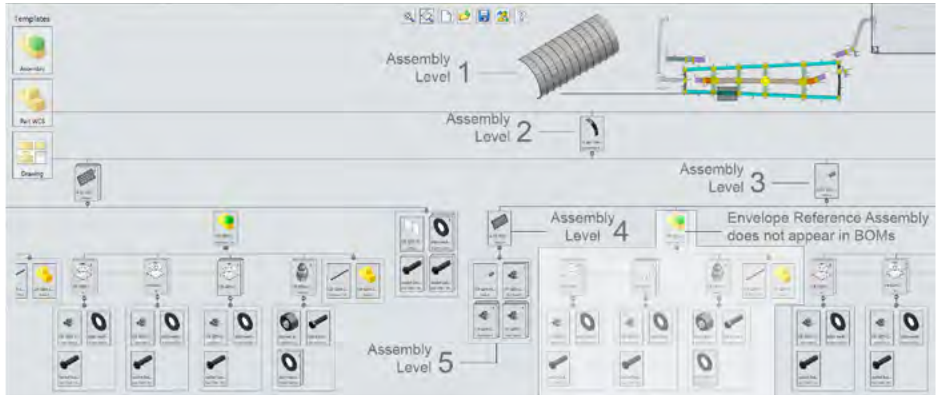




Data driven manufacture

Linking modelling tools direct to manufacturing processes is a very powerful way of increasing productivity by eliminating e.g. the need to output and check drawings, reduce the possibility of errors being introduced and facilitating mass customisation.

The manufacture of the complex moulds for the tunnel lining sections to the Elizabeth Line stations was undertaken by CNC (computer numerical control) milling machines linked directly to the design model.



Above:
Authoring software component 'tree' showing nesting of assemblies and sub assemblies

Below:
Complex mould for a tunnel lining element, milled directly from the model by CNC machine.

Detailed construction + logistics planning

As the installation of the DfMA or off-site elements becomes increasingly efficient, their interaction with other systems will become critical i.e. the programme benefits that off-site brings will be lost if the remainder of the construction process cannot keep up.

It will therefore be important to optimise and rehearse the site assembly sequence to ensure that the full benefits are leveraged.

The PPI Reasons for Change included in the introduction showed that the most significant causes of low productivity are:

- Operational stoppage;
- Labour shortage;
- Lack of materials;
- Lack of design information.

As a result, site installation must be highly productive and well planned to leverage the full benefits of DfMA.

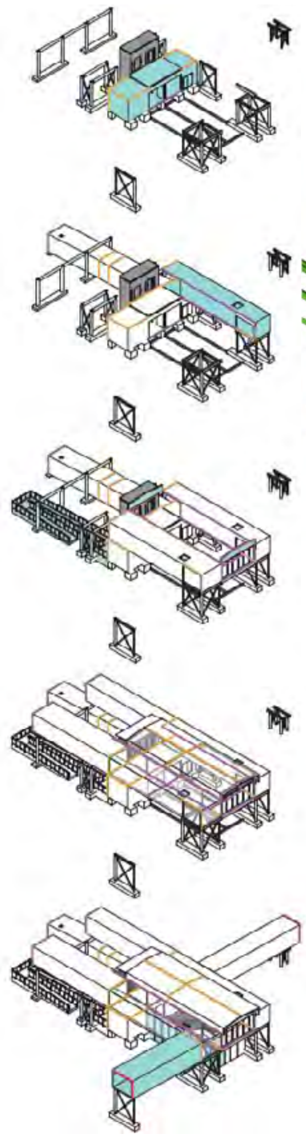
The advanced use of BIM generates highly accurate (in some cases fabrication quality) representations of the final building. This will allow virtual build exercises which will be used to optimise assembly sequence, test health and safety aspects and create highly detailed assembly manuals and installation programmes.

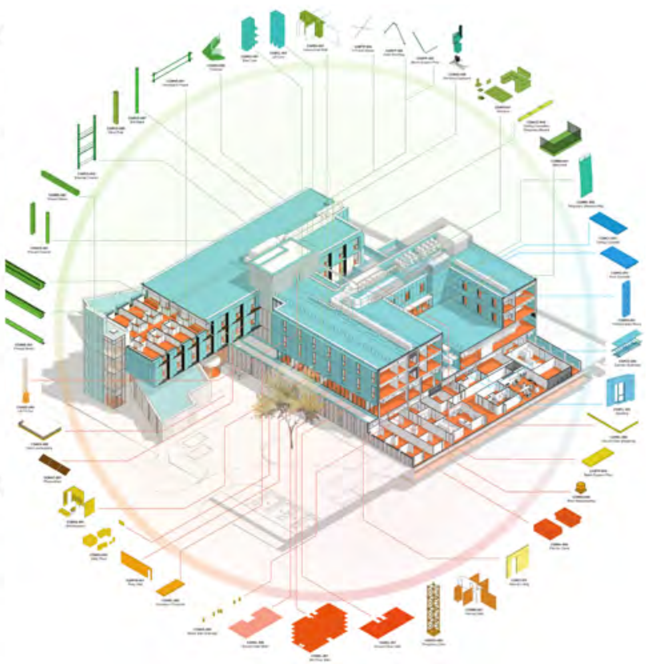
Activities

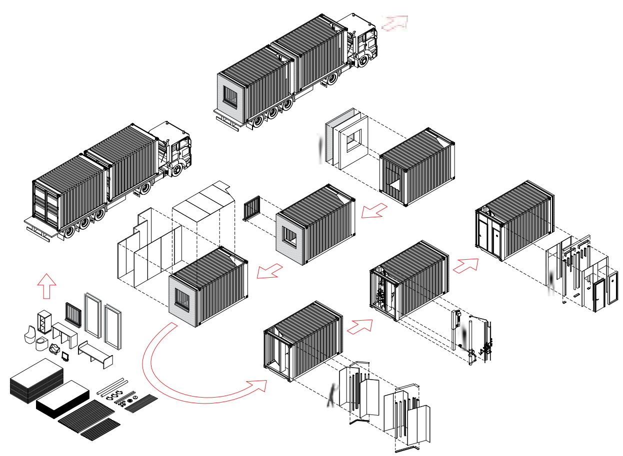
Include install time (i.e. 'when') and duration ('how long') as attributes in the models to enable the following:

- Linking the programme to the model so that the build sequence can be shown in a clear visual manner;
- Testing construction sequences and scenarios;
- Assessing and improving health + safety impacts.

cont'd







Detailed construction + logistics planning cont'd

Interface and collaborate with Tier delivery partners regarding:

- Planning logistics (placement of cranes and hoists, delivery of materials vs. programme etc.);
- Planning and optimising temporary works;
- Progress reporting from site, planned vs. actual progress, time slice reports etc.

Outcome - Pre-construction

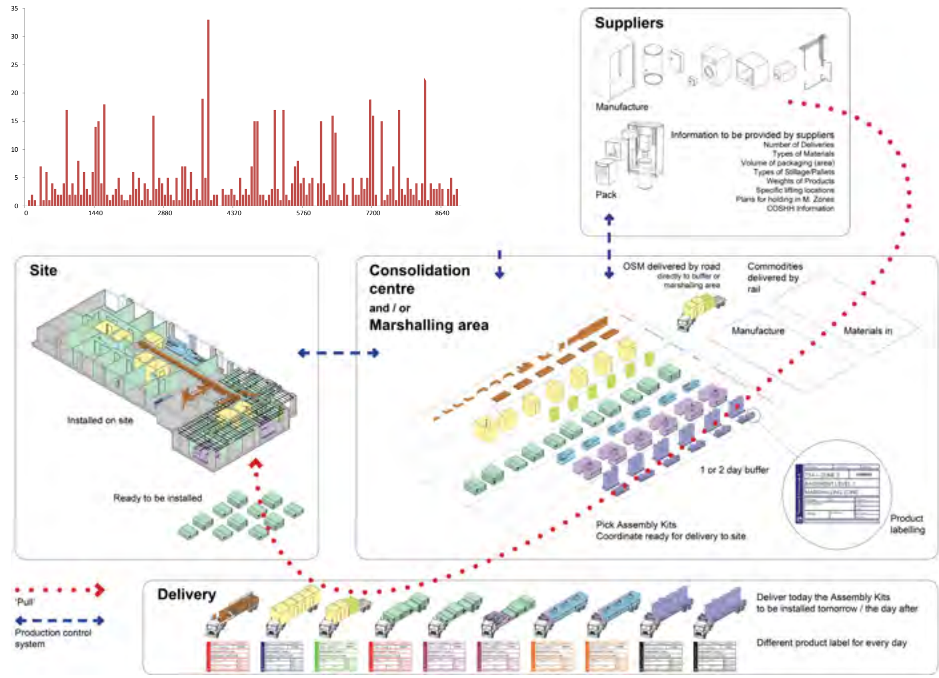
- Programme and construction sequence tested virtually to create optimised programme;
- Critical path identified and protected;
- Logistics plans tested for difficult parts of the programme;
- Health and safety reviews carried out for complicated build sequences;
- Temporary works erection and removal tested against permanent works.

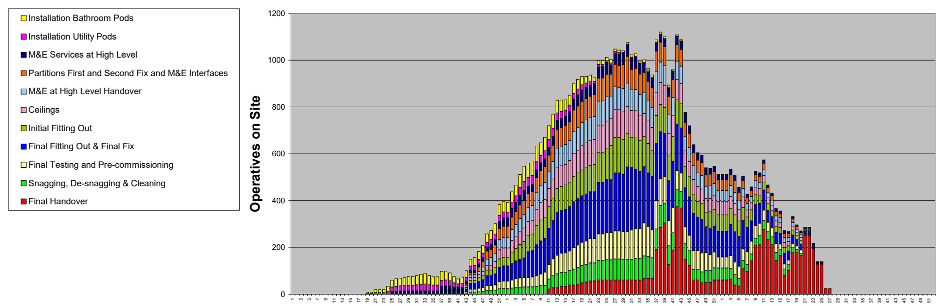
Outcome - Construction phase

- Construction status fed back to the models for visual reporting;
- Feedback loops in place to identify activities which are creating a barrier to timely delivery;
- Accurate reporting and mitigation strategies for Early Warning Notices etc.
- Accurate forecasting for impacts of change.

Outcome - Handover

- Plan commissioning activities, based on which systems are interlinked and must be tested in a particular sequence etc.
- Optimise handover schedule;
- Review phased handover scenarios - testing which areas can be made fully functioning and safe for the client to commence fit out or occupation.





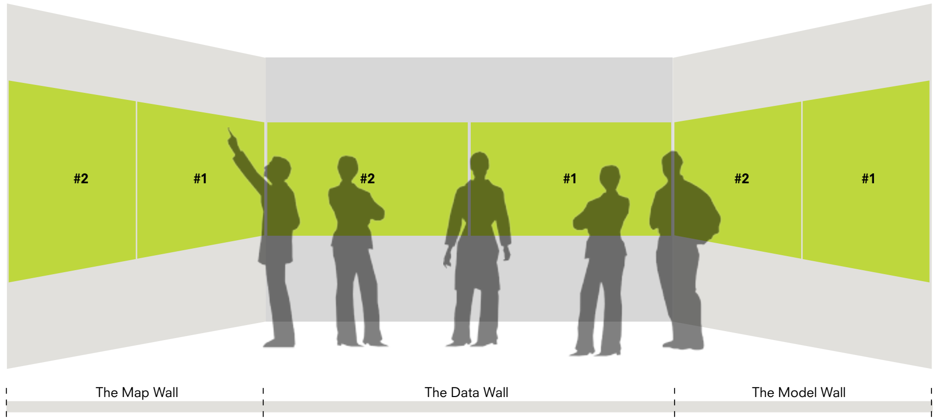
Production Control + Collaboration Room

For Highways England, Bryden Wood have established a 'Project Control Room' which brings together a range of models, data and live mapping in formation to allow:

- Decision making tools, for on site team, to resolve and manage site activities and events, during the construction phase;
- Visualization of 'Event' based data of actual site activity, including operatives and resources;
- Visualisation and analysis of relevant geo-spatial data sets (current and historic, such as traffic flow data;
- Automated reporting and communication of construction processes and activities to Highways England and other stakeholders.

The first Production Control was implemented on the Smart Motorways project M1 Junction 23a to 25.

Highways England have since installed a mirror site at their headquarters.



Above:
Diagram showing the layout of the Production Control Room

Below:
Live Production Control Room being used for M1 Junction 23a to 25

cont'd

Production Control + Collaboration Room cont'd

The Production Control Room provides a single version of the truth:

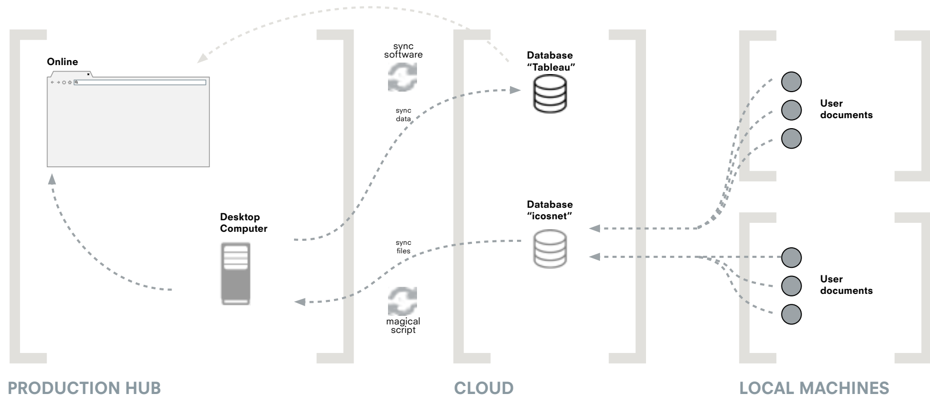
- All project data stored in shared location (rather than across multiple machines);
- Open access to all relevant project data in digital form (rather than printing drawings and using post-it notes);
- Contextualise information dynamically, as needed (rather than working from static, discrete and often superseded documents).

Provides access to planning data from all levels, in a coordinated and interlinked way:

- High level Gantt chart and Tilos programme;
- Three week look ahead;
- Daily plan.

Increased productivity across the project is facilitated via:

- Live site access plans provided to ensure correct deliveries are available at the right point on the site;
- Operative training records available to better understand available skills within teams;
- View live traffic to understand accidents, incidents and congestion;
- Access up to date design information from a single location, including drawings and model files;
- Transparent reporting of progress and problems;
- High level cost planning/ project spend tracked against planned;
- Environmental survey data viewable in the same context of the design and construction activity;
- 4D model linked to construction programme, with detailed studies of specific areas (including custom navigation for ease of use).

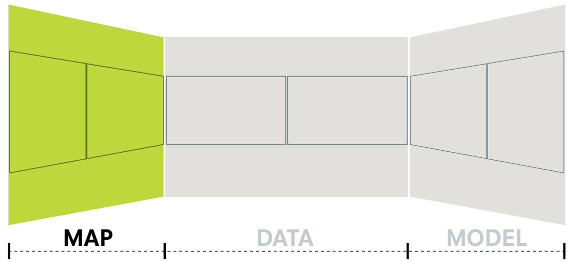


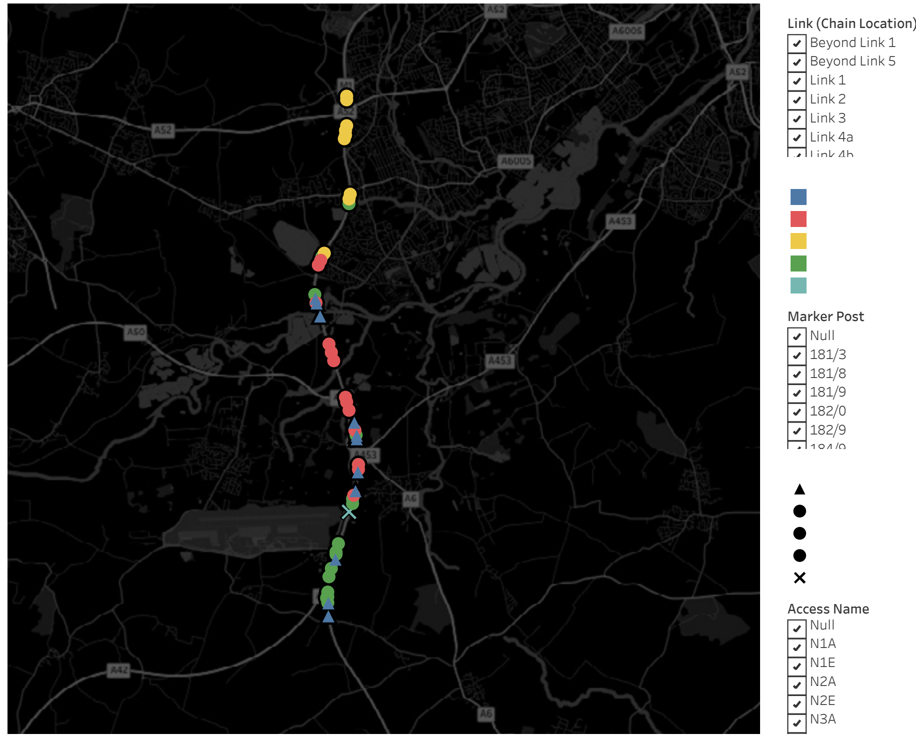
Refresh diagram showing links between the production hub and project team local machines

The Map Wall

The Map wall use cases include:

- Heat map of activity (e.g. hot / cold);
- Ability to see where gaps can be filled with other activities;
- Improve customer perception - if we fill the gaps and always have people working;
- Link all of the information related to the planning;
- Ability to use the map for detailed planning activities;
- Activities: Start, Finish, Resources (people and plant);
- Materials (continuous, single, take away);
- Traffic Management;
- Access Plan (entrance and exit point status);
- Heat map of scheduled person/ gang locations, including subcontractors and deliveries, to inform Works Access Planning;
- Delivery planning - when and where deliveries are taking place;
- Where clashes with other activities may occur;
- Daily activity status/ progress tracking;
- What has been completed and what is outstanding;
- Including not just works, but quality activities too.

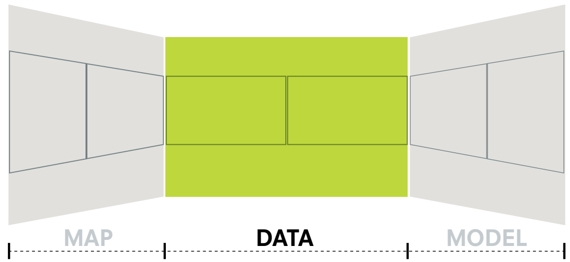


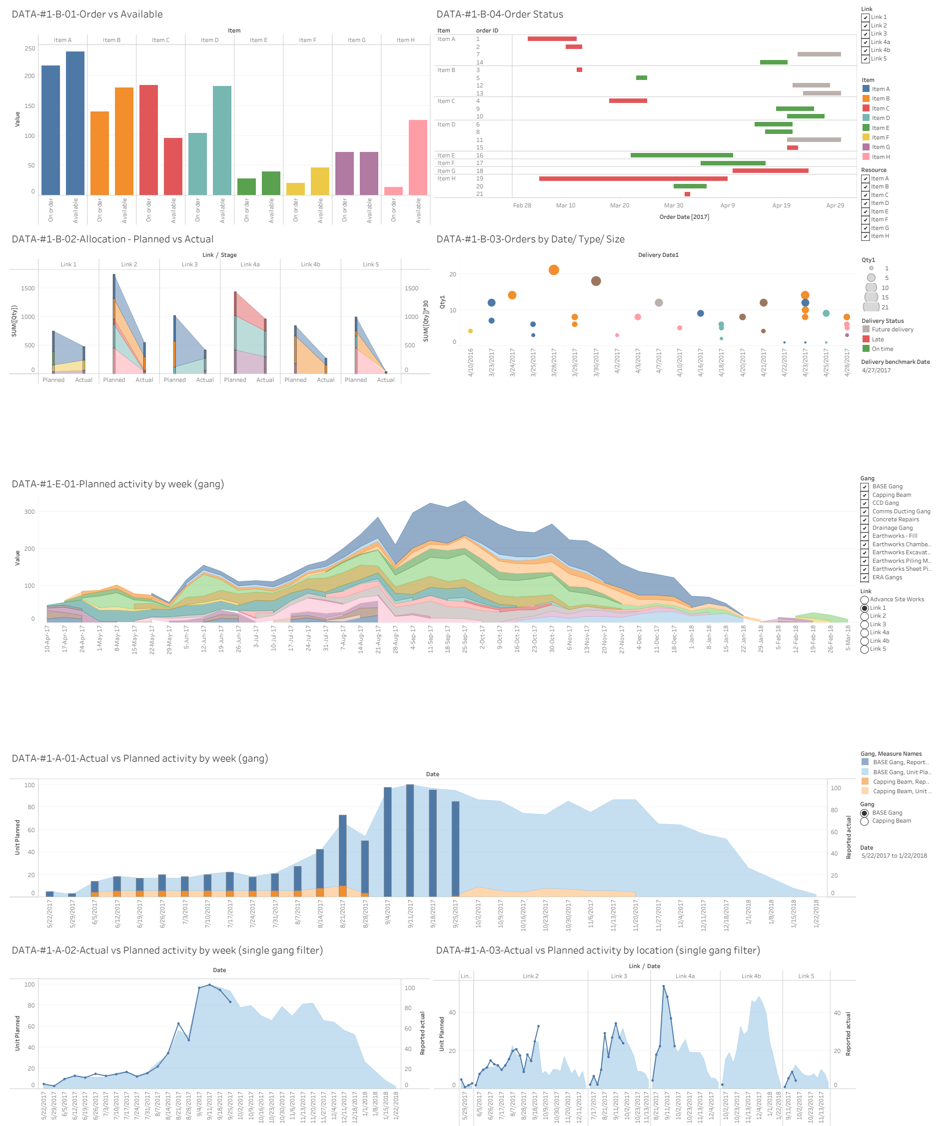


The Data Wall

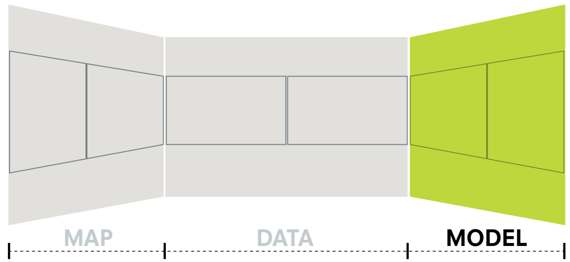
The Data wall use cases include:

- Adherence to programme;
- Learn from previous performance;
- Planned Percentage Complete (PPC);
- Visibility of real progress vs. planned progress;
- Weekly and monthly performance;
- Trends around lack of adherence, learn from previous performance;
- Enable strategic level decision making;
- How much has been delivered vs. ordered;
- Ability to see what has actually been delivered to the ganger, and reorder quickly for the next day if needed;
- Delivery management - when and where deliveries are taking place?
- See where deliveries are taking place and where clashes with other activities may occur;
- Visibility of the amount of work completed vs. costed (e.g. earthworks, sheet piling, 1000m clearance vs. 500m clearance).



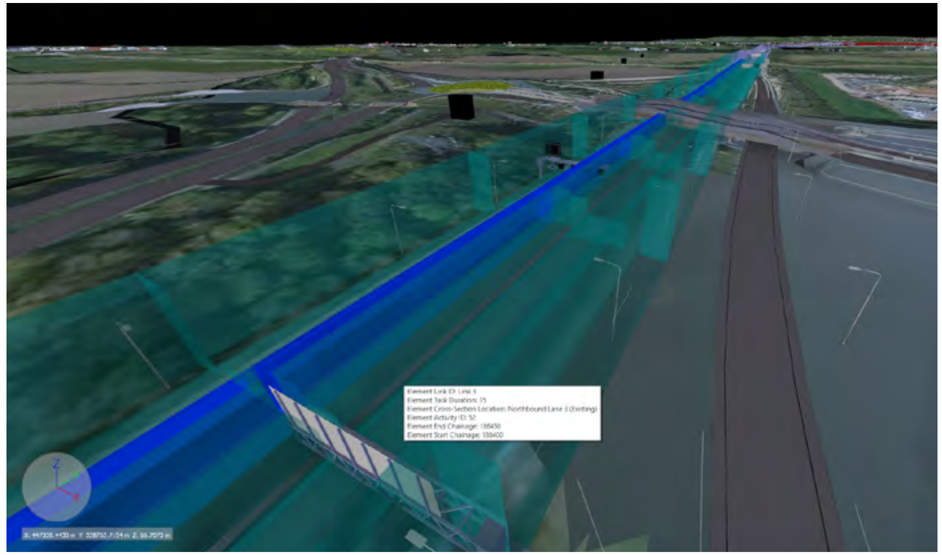


The Model Wall



The Model wall use cases include:

- STATs model - services (gas, electric etc.)
- Visibility of trial hole results
- Critical path analysis:
    - Understand what the critical path activities are, as well as the 'nearly critical path activities'.
    - Understand what has to be done today/ this week to stop an impact on the critical path



‘Mission control’

The previous sections have shown how data can be captured and processed from the smallest scale (individual materials) to the largest (nationwide geographic information systems).

The use of highly standardised BIM libraries, enhanced with data gathered through the virtual and physical prototyping stages, will create a rich information benchmark that can be analysed as described in earlier sections.

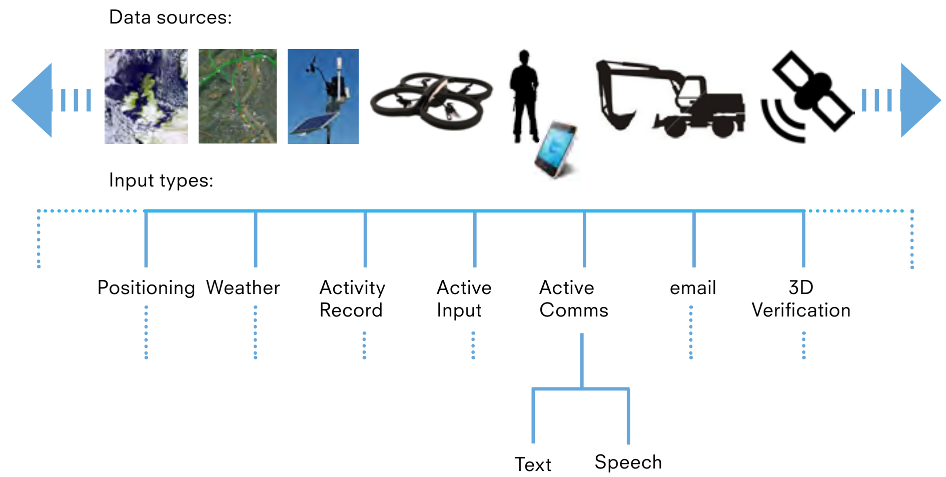
The use of standardised solutions at the scale and geographic diversity of the government estate, combined with open and collaborative ways of working, offers the chance to take this further and create an exemplar project controls system for the BIM-enabled industry.

By combining all of the available data sets, bridging the traditional boundaries (physical and imagined) between ‘the site’ and ‘the factory’ a data flow would link manufacturing centres to the construction zone.

High quality, accurate data would be received from a range of existing sources including:

- Operatives - activity recording using GPS enabled smart phones with custom apps;
- Vehicles - GPS tracking for all construction vehicles, recording all delivery journeys as well as on site activity;
- Mesh-network enabled CCTV monitoring systems using balloons;
- Drone technology for image and video capture;
- Digital weather stations / sensors monitoring air and ground conditions;
- Photogrammetry / laser scanning for site topography;
- Live traffic reporting;
- Weather satellite data and services.

cont’d



Data collection categories:

Active
- Participants send info about activity
- Detailed but less robust

Passive
- Participants activity is monitored
- Less detailed but more robust

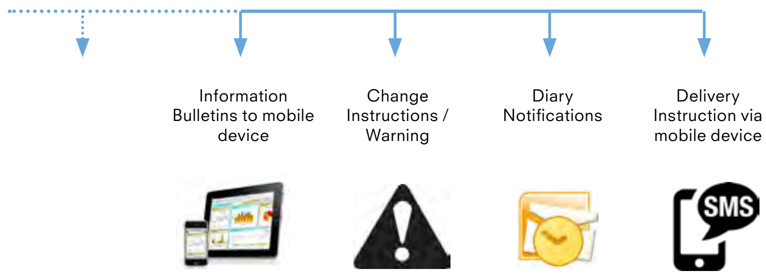
Mission control will use the data capture and analysis to provide targeted communications to the project team and operatives across the site including:

- Better project planning prior to construction through detailed scenario studies;
- Data-rich, visual feedback to assist project planning decision making;
- Accurate benchmarking of carbon footprint before construction and using it as a driver for project planning;
- Simulation of unusual/ extreme events, their potential impacts and possible mitigation;
- Familiarisation of the monitoring system that will be used during construction;
- Long range forecasts for factory production with long lead time;
- Weekly plans with detailed activity schedules;
- Daily updates to site operatives for optimum deployment of workforce;
- Hourly updates with weather warnings;
- Real time redirection of deliveries to avoid traffic or to hold points to ease congestion at site entrances.

This would be used for more agile and responsive project controls, linking suppliers, logistics and sites in a highly organised network.

Integrating live reporting from subcontractors and suppliers would facilitate:

- Higher productivity;
- Better levelling of supplier workload;
- Just in time delivery;
- Fewer on site movements;
- Reduced waste.



Tel. +44 (0)20-7253-4772
Email info@brydenwood.co.uk
brydenwood.co.uk

Bryden Wood
100 Gray's Inn Road, London
WC1X 8AL, United Kingdom

Bryden Wood

CONSTRUCTION
INNOVATION HUB