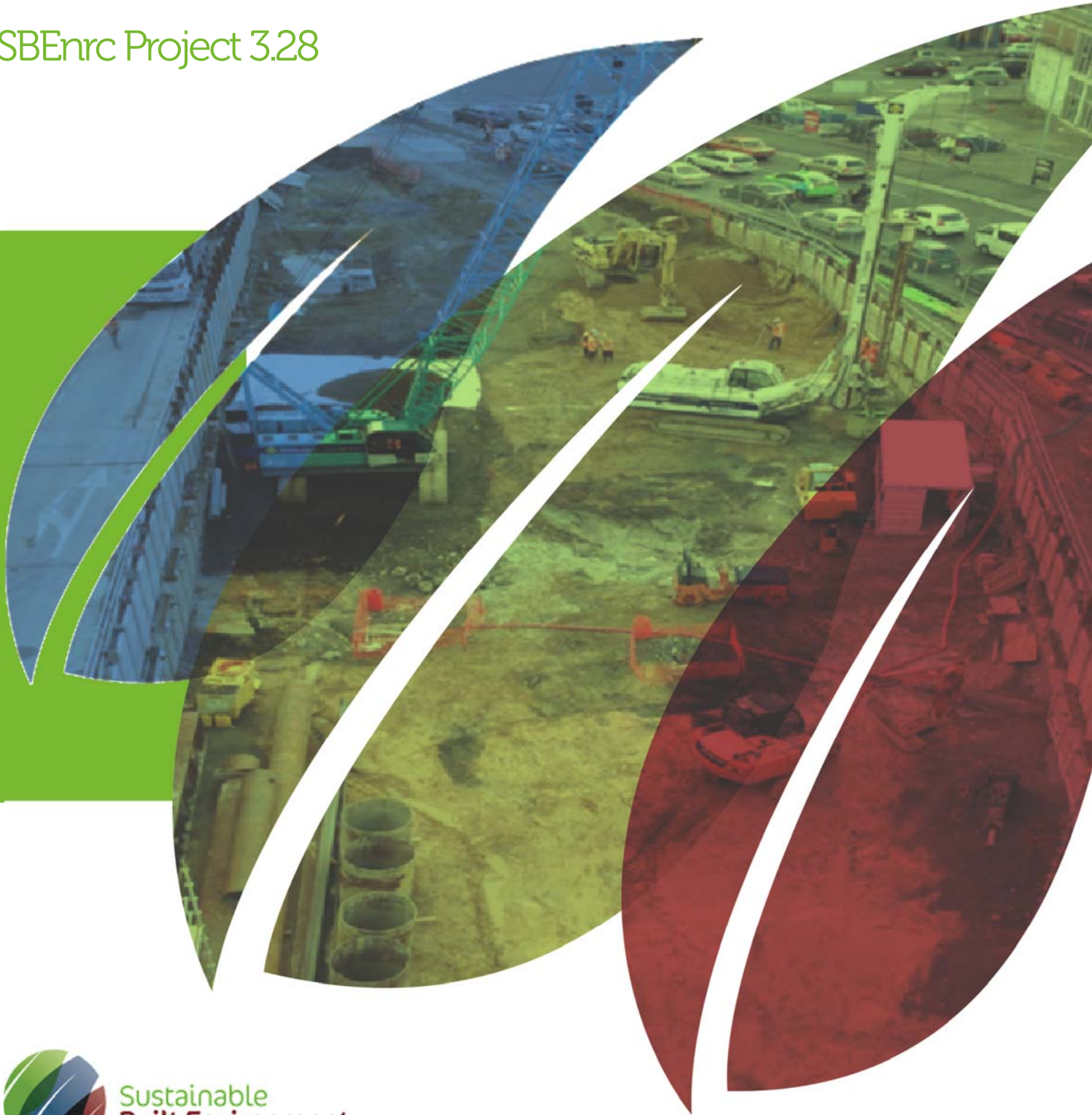


National BIM Guidelines and Case Studies for Infrastructure

SBEnc Project 3.28



Sustainable
Built Environment
National Research Centre

April 2017



Core Members

The Sustainable Built Environment National Research Centre's collaboration with our partners is adding significant value to the effectiveness and long-term sustainability of Australia's built environment industry. This research would not have been possible without the ongoing support of our industry, government and research partners:



Preface

The Sustainable Built Environment National Research Centre and its predecessor, the Cooperative Research Centre for Construction Innovation, has been committed to leading the Australian property, design, construction and asset management industry in collaborative research and innovation since 2001. We have been dedicated to disseminating practical research outcomes to our industry, to improve business practice and enhance the competitiveness of our industry. Developing applied technology and management solutions, and sharing useful industry knowledge is what our Centre is all about.

We look forward to your using the results of this applied research and working together, transforming our industry in enhanced business practices, safety and innovation.



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Acknowledgement

Thanks to the following organisations for providing the BIM case studies



NZ TRANSPORT AGENCY
WAKA KOTAHI



Executive Summary

To date, the level of BIM implementation in the transport infrastructure sector is a few years behind that for vertical building construction. Compared with the building sector, the provision of infrastructure usually involves physical and organisational structures addressing society needs which are mainly owned and managed by governments. Almost all published BIM guidelines/standards are targeted to the building sector. The purpose of this BIM guideline is to promote the application of BIM in infrastructure projects and to ensure data fidelity and continuity across the lifecycle of a project, thereby improving quality and productivity.

Infrastructure in this guideline refers in particular to main roads, highways, bridges and tunnels, which each have their own construction methods and characteristics. The experiences and investigation data from the building sector are generally not relevant for infrastructure. This project has identified and redefined 41 BIM uses in infrastructure, which include 18 BIM uses in the design stage, 11 in the construction stage and 12 in the operational stage. Regarding BIM model development, seven Levels of Detail (LODs) have been defined from LOD0 to LOD6. LOD0-LOD4 come from the CityGML standard and are useful in the infrastructure planning and design stages. LOD5 and 6 are developed at the model element level and used to support infrastructure construction and operation.

Managing the development of a BIM model requires skills that are similar to managing the real thing. BIM production is sometimes done by people who understand computer technology but do not necessarily understand how to manage the workflow into a BIM model from multiple sources. In order to improve the quality of BIM models, BIM model management requires more rigorous setting of modelling guidelines, BIM roles and responsibilities, and BIM model assessment.

To bring together the information and engage in BIM, effective and coordinated collaboration is essential. Two types of collaboration workflows have been developed, for individual discipline modelling and cross-disciplinary model design respectively. In addition, BIM relevant issues are discussed such as ownership, contractual implications and risk profile.

Five case studies were conducted to demonstrate the BIM capacities in infrastructure projects: Upgrade of Great Eastern Highway (Australia), Moreton Bay Rail project (Australia), Memorial Park Underpass (New Zealand), Perth's Light Rail Network (Australia) and Auckland City Rail Link (New Zealand).

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1 Introduction

1.1 What is BIM?

Building Information Modelling (BIM) is an intelligent 3D model-based process to inform and communicate project decisions. Parametric Design, visualisation, simulation, and collaboration provide greater efficiency for all stakeholders across the project lifecycle to improve the design, construction and operations of facilities. The National Building Information Model Standard Project Committee in the USA defines a BIM as:

“a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for

information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition. A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder.”

1.2 Purpose and scope

In recent years, while BIM has become an important strategy in building construction to improve productivity and profitability, uses of BIM are just beginning in infrastructure construction. However, the application of BIM for Infrastructure is rapidly accelerating as owners and engineering service providers increasingly recognise the benefits of 3D modelling using intelligent objects.

The purpose of this BIM guideline is to promote the use of BIM in infrastructure

projects and to ensure data fidelity and continuity across the lifecycle of a project improving quality and productivity.

This BIM guideline focuses on four types of infrastructure: Main roads, Highways, Bridges and Tunnels. Also, it is used as a reference guide to implement BIM for infrastructure and provides BIM uses, main elements with LOD (Level of Detail), modelling guidelines and model assessment/quality control, BIM collaboration, relevant issues and case studies.

1.3 Existing relevant guidelines

A total of 42 guidelines from 10 countries for Infrastructure document, which were collected and analysed (as shown in Table 1). They were used as reference guides in the development of this National BIM Guidelines and Case Studies

See the detailed list of each existing BIM guideline in **Appendix A**.

Table 1: Existing BIM guidelines and standards

Country	Quantity	Year
Australia	4	2009, 2011, 2012
USA	24	2007-2013
Hong Kong, China	1	2011
Denmark	1	2007
Spain	1	2011
Finland	2	2007, 2012
The Netherlands	1	2012
UK	4	2011-2013
Norway	2	2011, 2012
Singapore	2	2010, 2012

1.4 Terms and definitions

1.4.1 Industry Foundation Class (IFC)

The IFC specification is a neutral data format to describe, exchange and share information typically used within the building and facility management industry sector. IFC is the international standard for openBIM (openBIM is a universal approach to the collaborative design, realisation, and operation of buildings based on open standards and workflows.) and registered with the International Standardization Organisation ISO as ISO16739. The IFC specification is developed and maintained by buildingSMART International (<http://www.buildingsmart.org/>), formally known as International Alliance for Interoperability, IAI). The official website to publish IFC and related specifications is [buildingsmart-tech.org](http://www.buildingsmart-tech.org) (<http://www.buildingsmart-tech.org/>).

1.4.2 City Geography Markup Language (CityGML)

CityGML is an open data model and XML-based format for the storage and exchange of virtual 3D city models. It is an application schema for the Geography Markup Language version 3.1.1 (GML3), the extendible international standard for spatial data exchange issued by the Open Geospatial Consortium (OGC) and the ISO TC211. The aim of the development of

CityGML is to reach a common definition of the basic entities, attributes, and relations of a 3D city model. This is especially important with respect to the cost-effective sustainable maintenance of 3D city models, allowing the reuse of the same data in different application fields.

1.4.3 Construction Operations Building Information Exchange (COBie)

COBie is a performance-based specification for facility asset information delivery. Two types of assets are included in COBie: equipment and spaces. While manufacturer's data for installed products and equipment may one day be directly available, COBie helps the project team organise electronic submittals approved during design and construction and deliver a consolidated electronic Operation & Maintenance manual with little or no additional effort. COBie data may then be imported

directly into Computerised Maintenance Management System and asset management software, again at no cost. The PDF, drawing and building information model files that accompany COBie are organised so that they can be easily accessed through the secure server directories already in place at the facility management office. The federal government's requirement for delivery of Real Property Inventory (RPI) information may be met by COBie.

1.4.4 Level of Detail (LOD)

In computer graphics, accounting for LOD involves decreasing the complexity of a 3D object representation as it moves away from the viewer or according to other metrics such as object importance, viewpoint-relative speed or position. From a BIM perspective, LOD is a measure of the amount of information

provided. The LOD for a BIM model must correspond to the needs of the modeller, the project engineer, and the estimators and schedulers. LOD identifies how much information is known about a model element at a given time. This "information richness" grows as the project comes closer to breaking ground.

1.4.5 Interoperability

In the context of BIM, interoperability is defined as the ability to manage and communicate electronic product and project data between collaborating firms', and within individual companies', design, procurement, construction, maintenance and business process systems.

1.4.6 Model Element

A Model Element is a portion of the Building Information Model representing a component, system or assembly within a building or building site.

1.4.7 Model Element Author (MEA)

The Model Element Author is the party responsible for developing the content of a specific Model Element to the LOD required for a particular phase of the project.

1.4.8 Request for Information (RFI)

A Request for Information (RFI) is a standard business process used by customers to collect written information regarding the capabilities of various suppliers, which will better inform buying decisions.



2 BIM uses in infrastructure



Infrastructure BIM Uses				
	Road	Tunnel	Rail	Bridge
Design	Site Analysis	Design Authoring	Surface Analysis	
	Land Survey	Performance forecasting	Constructability Reviews	
	Design Reviews	Visualisation	Design Changes	
	Design Evaluation	Design Integration	Quantity Take-off	
	Cost Estimation	Code Validation	Structural Analysis	
	Point Clouds	Signal Sighting	Traffic Simulation	
Construction	Field Survey	Site Layout and Logistics	Virtual Scheduling and Work Planning	
	Construction Inspection	Material Management	Progress Tracking	
	Quality Tracking and Reporting	Safety planning and Control	Cost Control	
	Equipment Management	Digital Fabrication		
Operation	Maintenance Scheduling	System Analysis	Asset Management	
	Disaster Planning	Record Modelling	Event Planning	
	Road/Rail Management	Transportation Management System	Traffic Volume Simulation	
	GIS Asset Tracking	Water Mitigation and Planning		

Fig. 1: BIM uses in infrastructure

2.1 BIM uses in design stage

2.1.1 Site Analysis

BIM/GIS tools are used to evaluate properties in a given area to determine the most optimal site location for a future project. Site conditions can dramatically impact development/construction costs and it is important for

clients to understand these potential impacts prior to making significant financial commitments. The site data collected is used to first select the site and then position the building based on other criteria.

2.1.2 Design Authoring

The design authoring purpose of the BIM uses is used to develop a Building Information Model based on criteria that is important to the translation of the infrastructure's design. Two groups of applications that are at the core of the BIM-based design process are design authoring tools and audit and analysis tools. Authoring tools create models while audit and analysis tools study or

add to the richness of information in a model. Most audit and analysis tools can be used for Design Review and Engineering Analysis BIM uses. Design authoring tools are a first step towards BIM and the key is connecting the 3D model with a powerful database of properties, quantities, means and methods, costs and schedules.

2.1.3 Surface Analysis

The surface analysis purpose of BIM uses is to generate detailed analysis of model objects such as the detailed volume analysis. All the analysis performed on the existing Surface can also be performed on proposed Surfaces. The

proposed design interventions can be assessed in terms of elevation, slope, aspect and hydrology, and cut and fill calculations can also be made to balance earthworks requirements .

2.1.4 Land Survey

Land surveying is based on optical measurement systems and allows the surveyor to compute the three-dimensional coordinates of the objects he or she identifies. It is a time-consuming process because it requires

the field operator to identify explicitly each point and line to be surveyed. This technique is particularly suitable for large-scale surveying aimed at producing topographic maps.

2.1.5 Performance Forecasting

The performance forecasting of BIM uses is one of the largest and has the most variance in its application from element to element. Within this purpose, detail analysis is conducted to predict future performance of the facility and facility elements. Some of the primary performance factors that should be considered include financial, energy, flow, scenario and temporal. Financial forecasting includes cost estimation of first cost of construction as well as the

life cycle cost of a facility. Scenario forecasting predicts performance of the facility during emergencies, such as fire, accident and others. Temporal forecasting predicts the performance of the facility over time to include building degradation and the timing for element replacement. Together this purpose of BIM Uses examines multiple facility variables and predicts facility performance.

2.1.6 Constructability Reviews

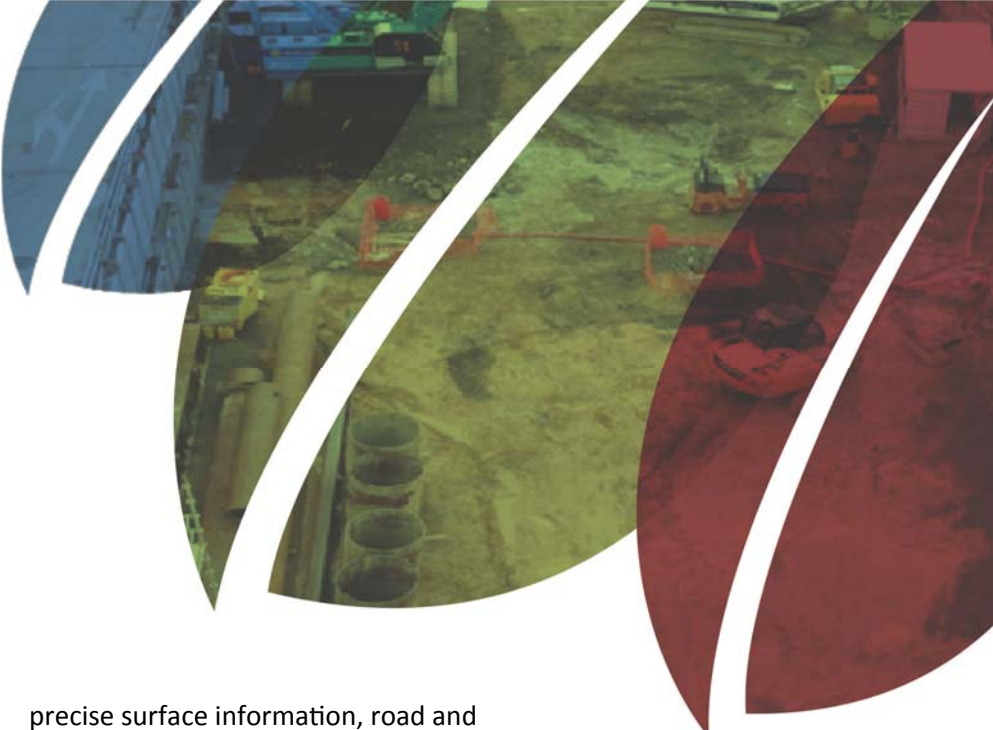
In this purpose of BIM uses, BIM is used for reviewing the building model and checking for coordination and buildability, along with plans and specification to determine constructability of the project and coordinate with other project participants. It can be used to enhance

existing systems related to construction sequence, equipment access, completed work and assembling difficult components. In this way, any misunderstandings can be reduced or cleared before getting out into the field, since all the important design details have been clarified.

2.1.7 Design Reviews

BIM is used to showcase the design to the stakeholders, evaluate meeting the program, and set criteria such as layout, sightlines, security, ergonomics and textures and colours, etc. Virtual mock-ups can be done in high detail even on a part of the infrastructure, like a pier of a bridge, to quickly analyse design

alternatives and solve design and constructability issues. If properly executed, these reviews can resolve design issues by offering different options by developing and evaluating its conceptual design alternatives in that single model.



2.1.8 Visualisation

As part of the communication purpose of BIM uses, using BIM to better visualise a facility is very powerful. BIM for Infrastructure software maintains fidelity between modelling, analysis and rendering applications in order to allow for quick and accurate visual representations of projects in a contextual environment by utilising

precise surface information, road and site designs and pipe network models. Visualisation is often used to support decision making about the facility's design or construction as well as support marketing efforts. It can also include walkthroughs and schedule visualisations.

2.1.9 Design Changes

With a dynamic framework, cross analysing surface information with pipe networks, roadway alignments and vertical profiles, and site grading, 3D modelling software can quickly adapt to design changes. Modifications to a vertical curve or the replacement of

adjacent sidewalks with landscaping, as well as modifications to pipe sizes or pavement depths are immediately realised in the model and recalculated to meet site conditions.

2.1.10 Design Evaluation

Using BIM tools, engineers can visually analyse designs beyond that which numeric values on a spreadsheet alone can communicate. Rotating a design three-dimensionally and performing automated clash detection analysis for

drainage, collection and utility networks in real time is made possible with these software tools. As project changes occur, adjustments are made in the software and engineers can review the effects immediately.

2.1.11 Design Integration

This purpose of BIM uses is to quickly consolidate different data files representing existing conditions, such as 2D CAD, GIS, raster and 3D models, into a single model. With the existing conditions model in place, designers then

sketch early-stage designs directly in that modelling environment or import detailed design information from Civil 3D to easily create project visualisations and simulations.

2.1.12 Quantity Take-off

In this purpose of BIM uses, BIM is used for counting or collecting the amount of specific facility elements. This purpose is often used as part of the estimating and cost forecasting process. During the design phase of a facility, quantities are defined broadly, represented by a range

and subject to change. In the construction phase, quantities become more certain and in the operations phase, quantities of elements can be readily calculated.

2.1.13 Cost Estimation

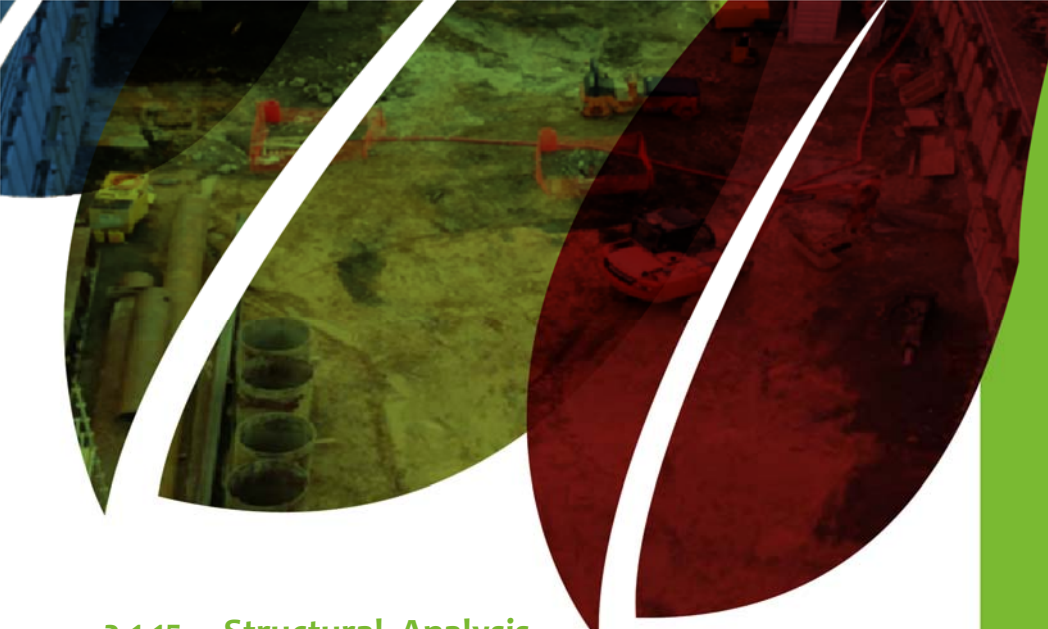
BIM can be used to assist in the generation of accurate quantity take-offs and cost estimates throughout the lifecycle of a project. This process allows the project team to see the cost effects of their changes, during all phases of the project, which can help curb excessive

budget overruns due to project modifications. Specifically, BIM can provide cost effects of additions and modifications, with potential to save time and money and is most beneficial in the early design stages of a project.

2.1.14 Code Validation

This purpose of BIM uses is implemented to validate facility information. This includes purpose checking facility information for accuracy to ensure that it is logical and reasonable. The validating BIM uses fall into three primary areas: prescription, functionality and compliance validation. Prescription validation ensures that the facility has the elements that were specified and programmed within the facility including the primary element of facility spaces or

rooms. The purpose of functionality validation is to ensure that the facility is constructible, maintainable, and usable. Will the facility perform the purpose for which it has been designed? Compliance validation confirms a facility's compliance with codes and standards to include construction codes, sustainability standards and others. Any time facility information that was developed in another process is checked for accuracy, it falls into the category of validating.



2.1.15 Structural Analysis

BIM data is utilised to determine the behaviour of a given structural system. With the modelling, minimum required standards for structural design and analysis are used for optimisation. Based on this analysis, further development and refinement of the structural design

take place to create effective, efficient and constructible structural systems. The development of this information is the basis for what will be passed on to the digital fabrication and construction system design phases.

2.1.16 Point Clouds

The term “Point Clouds” has been floated around for a long time, but within the last few years there has been a deluge of technology advancements and drop in cost making the equipment to capture the built environment 3-dimensionally an economically viable option for architecture, engineering and construction industries. There are many different methods for acquiring a point cloud such as aerial LiDAR, mobile laser scanning, sonar and 3D photogrammetry.

What we can use these resulting point clouds for can vary from surface models for environmental studies, transportation engineering, structural design, pipe network modelling, to visualisation. The point cloud surveys have the advantages that they can be completed more quickly, provide fully detailed coverage of the area and require fewer return visits to pick up any missed details. This has great benefits in reducing the need for trackside surveys.

2.1.17 Signal Sighting

The BIM approach has provided a major opportunity to design and test the new signalling proposals well ahead of a scheme being on site. The 3D modelling has also focused attention on areas where early design focus is required to

establish feasibility. An example of this is the need to bring forward design of small -parts fixing arrangements for overhead line equipment close to critical signals, where there is a risk of these elements obscuring the signal.

2.1.18 Traffic Simulation

As the BIM advances to the broader infrastructure space, this ability to automate the performance of infrastructure design with traffic simulation becomes really compelling. Programming provides the ability to test

out different scenarios regarding traffic patterns to optimise design in real time. This adds to the intelligent modelling capabilities of Autodesk by taking the design, combining it with traffic data and visualising it within a real-world context.

2.2 BIM uses in the construction stage

2.2.1 Field Survey

Collection and gathering of information at the local level by conducting primary surveys is called field survey. It is a basic procedure to understand the existing surroundings. BIM and laser scanning can effectively improve traditional survey methods through accurately capturing detailed information about existing conditions and rapidly producing a 3D model-based representation of the existing environment for the project team.

The project team can leverage detailed models built for trade coordination or other purposes and accurately lay out building systems in the field exactly as planned during the 3D model-based coordination process. BIM-based construction layout not only increases the level of layout precision, but also takes less manpower than traditional layout methods. This confidence and trust level is based on a reliance of the accuracy of the BIM model.

2.2.2 Site Layout and Logistics

A site layout plan is a construction plan prepared by the contractor as part of their mobilisation activities before work on site commences. The 3D model needs to include: locations of cranes with radii and capacities, site offices, welfare facilities, off-loading and storage areas, sub-contractor facilities, car parking, entrances, temporary roads, separate pedestrian access, vehicle wheel washing

facilities, hoarding details, signage and temporary services (i.e. electrical power, lighting, water distribution and drainage, information and communications technology installations, site security systems, etc.). With BIM and intelligent algorithms, a site layout scheme can be automatically generated and dynamically optimised.

2.2.3 Virtual Scheduling and Work Planning

A traditional project schedule is based on a Gantt chart and just shows the sequence of each activity. It is hard to assess and evaluate the constructability of the schedule. With BIM, project managers can easily implement virtual project scheduling so as to eliminate collisions between activities, such as

resource collision, space collision and time collision. 4D simulation (3D models with the added dimension of time) is a powerful visualisation and communication tool that can give a project team, including the owner, a better understanding of project milestones and construction plans.

2.2.4 Construction Inspection

Building a new infrastructure project is a complex process. Mistakes may not be discovered in a timely way through a traditional approach which relies heavily on personnel's experience. In addition, it is time-consuming to search for the right information from traditional paper-based specifications and codes onsite. With

BIM implementation, all the inspection and testing information are linked to a 3D infrastructure model. Workers can easily get the right information at the right time at the right place. BIM can also enable real time inspection feedback so as to record and track the inspection progress.

2.2.5 Materials Management

The role of materials management is to account for and maintain responsibility for goods received at the site. This includes the delivery, tracking and maintenance of big prefabricated components (i.e. pier, girder and truss) in the field along with small construction support materials such as scaffold and consumables. The materials management group is responsible for all lay-down yard and warehouse activity on a project. They coordinate closely with home and regional offices to maintain schedule and quality expectations.

climate-controlled spaces. Working with engineering and construction personnel, preliminary plans for site access, resources and strategy are developed. In addition, BIM supports multiple-user access, to receive, track and control all project deliverables and materials.

With BIM implementation, materials management can be involved in project early stages. During the proposal stage, a detailed plan is produced outlining key requirements for outdoor, indoor and

2.2.6 Progress Tracking

Typical practice for progress tracking mostly depends on foremen daily or weekly reports which involve intensive manual data collection and entail frequent transcription or data entry errors. These reports are then studied by field engineers and/or superintendents along with 2D as-planned drawings, project specifications and construction details to review the progress achieved by that date. After that, they study the construction schedule to identify the work planned to be done by that date. This requires a significant amount of

manual work that may impact the quality of the progress estimations. BIM models integrated with laser scanning and mobile computing are being implemented in the infrastructure industry and have shown big benefits for supporting progress tracking. When combining 3D object recognition technology with schedule information into a combined 4D object oriented simulation, a project manager can effectively assess current construction progress and make timely decisions if a schedule delay appeared.

2.2.7 Quality Tracking and Reporting

BIM models provide quality assurance/quality control information for a quality manager to help proactively identify trends and minimise contractor risk. Quality manager can create and automatically distribute work-to-complete lists for trades and other parties. A field quality check worker can create and manage issues and checklists

on a mobile device. A quality manager can check the current status of all the project quality issues and report to the project manager. In addition, in order to improve the productivity of a quality check and reduce expensive rework, a quality checklist for each task can be embedded into a BIM model.

2.2.8 Safety Planning and Control

Construction safety and environmental plans must clearly describe how these and other risks will be managed on each project, what control measures will be used and how their effectiveness will be monitored and reviewed. Safe work method statements are also required for all work regarded as high risk construction work, or prescribed activity. In the traditional process, the work method statements are firstly identified by the project coordinator through a preliminary project risk assessment. Then, contractors may request a copy of this assessment to help in preparing their own work method statements by

contacting the project coordinator. It is difficult to identify and address all the main safety hazards of the planned job. BIM can provide a virtual construction platform and safety simulation environment for all the parties to develop a better construction safety plan. A BIM-based safety plan can visually explain how the contractor intends to manage those safety risks to the contractors' own employees or subcontractors. In addition, BIM-based orientation, introduction, education and supervision are possible ways to reinforce safety communication by visualisation.

2.2.9 Cost Control

For the purpose of construction cost control, it is not sufficient to consider only the past record of costs and revenues incurred in a project. Good managers should focus upon future revenues, future costs and technical problems. For this purpose, traditional cost control schemes are not adequate to reflect the dynamic nature of a project. 5D BIM refers to the intelligent linking of individual 3D components or assemblies with schedule constraint and

cost-related information. The construction of the 5D models enables the various participants (from architects, designers, contractors to owners) of any construction project, to visualise the progress of construction activities and its related costs over time. As changes or discrepancies between the plan and the realisation occur, the project schedule and cost estimates can be automatically modified.

2.2.10 Equipment Management

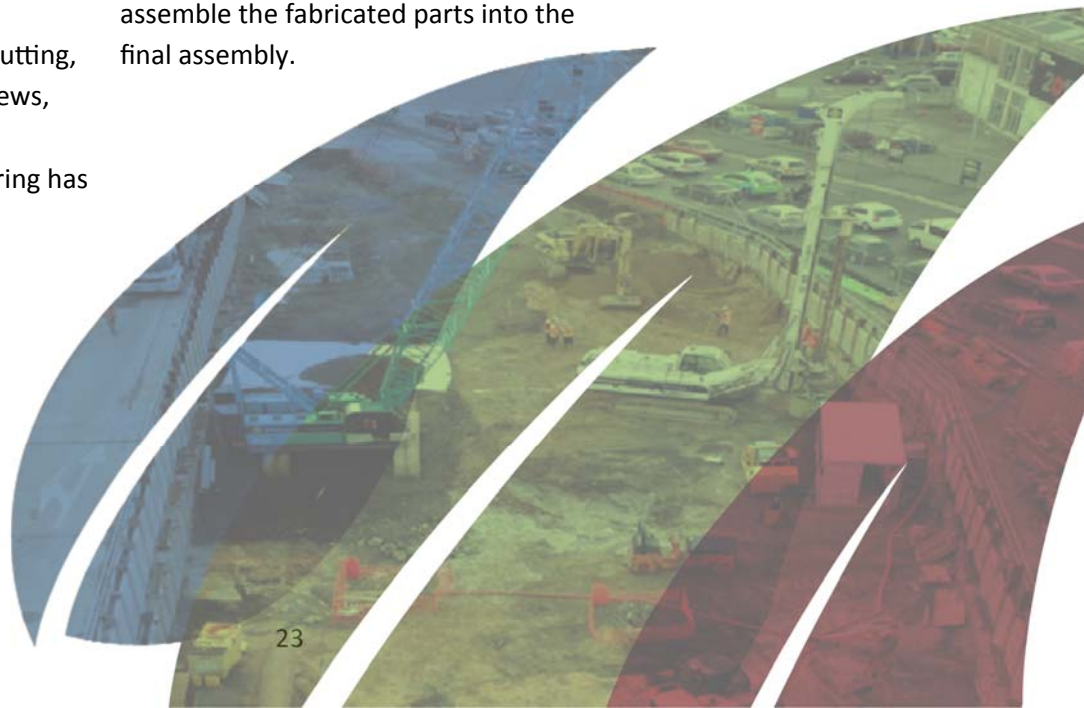
Managing cost and revenue on equipment is critical to success in the competitive construction market. BIM-based construction equipment management can help a project manager to schedule downtime to fit project workload. Status of every equipment

type can be integrated into a BIM model, such as maintenance schedules, complete service history and work arrangement. A project manager can develop a scientific equipment management scheme to improve and ensure maximum utilisation.

2.2.11 Digital Fabrication

A process that uses digitised information to facilitate the fabrication of construction materials or assemblies. Some uses of digital fabrication can be seen in sheet metal fabrication, structural steel fabrication, pipe cutting, prototyping for design intent reviews, etc. It assists in ensuring that the downstream phase of manufacturing has

minimum ambiguities and enough information to fabricate with minimal waste. An information model could also be used with suitable technologies to assemble the fabricated parts into the final assembly.



2.3 BIM uses in operation and maintenance stages

2.3.1 Maintenance Scheduling

The functionality of the infrastructure (girder, pier, pavement etc.) and equipment serving the infrastructure (mechanical, electrical, sign and signal, etc.) are maintained over the operational

life of a facility. A successful maintenance program will improve building performance, reduce repairs, and reduce overall maintenance costs.

2.3.2 System Analysis

Tracking performance data from the infrastructure systems and comparing these values to design model predictions enables BIM operator and facility managers to ensure that the building is operating to specified design and sustainable standards and identify opportunities to modify operations to

improve system performance. A designer can also use this data to validate and refine their prediction models and evaluate the impact of proposed materials and system changes to improve performance.

2.3.3 Asset Management

An organised management system is bi-directionally linked to a record model to efficiently aid in the maintenance and operation of a facility and its assets. These assets, consisting of the physical components, systems, surrounding environment and equipment, must be maintained, upgraded, and operated at an efficiency which will satisfy both the owner and users in the most cost effective manner. It assists in financial decision-making, short-term and long-term planning and generating scheduled work orders. Asset management uses the

data contained in a record model to populate an asset management system which is then used to determine cost implications of changing or upgrading building assets. The bidirectional link also allows users to visualise the asset in the model before servicing it, potentially reducing service time. Team competencies are going to need ability to manipulate, navigate, and review a 3D Model and manipulate an asset management system.

2.3.4 Disaster Planning

Emergency responders would have access to critical building information in the form of a model and information system. The BIM would provide critical building information to the responders that would improve the efficiency of the response and minimise the safety risks. The dynamic building information would be provided by a building automation system (BAS), while the static building information, such as floor plans and equipment schematics, would reside in a BIM model. These two systems would be integrated via a wireless connection and

emergency responders would be linked to an overall system. The BIM coupled with the BAS would be able to clearly display where the emergency was located within the facility, possible routes to the area, and any other harmful locations within the facility. Team competencies are going to need the ability to manipulate, navigate, and review a BIM model for facility updates, ability to understand dynamic building information through BAS and the ability to make appropriate decisions during an emergency.

2.3.5 Record Modelling

A process used to depict an accurate representation of the physical conditions, environment, and assets of a facility. The record model should, as a minimum, contain information relating to the main architectural and MEP elements. Additional information including equipment and space planning systems may be necessary if the owner intends to utilise the information. Furthermore, with the continuous updating and improvement of the record model and

the capability to store more information, the model contains a true depiction of space with a link to information such as serial codes, warranties and maintenance history of all the components in the facility. The record model also contains information linking pre-build specification to as-built specifications. This allows the owner to monitor the project relative to the specifications provided.

2.3.6 Event Planning

The BIM operator has to put the Facility Management System (FMS) data into the system based on as-built BIM data. When the object information has changed by the space program, remodelling, renovation and expansion etc., the BIM operator has to renew the BIM data.

The BIM operator has to check and monitor the facilities and input the BIM

based checking data to FMS for maintenance inspection, replacement of parts, space operation & adjustment and renovation & expansion.

The BIM operator must input the final as-built BIM data to FMS and also has to keep the original BIM data.

2.3.7 Road/Rail Management

BIM road and rail infrastructure management solutions help the user collect, maintain and analyse these assets, delivering a central platform upon which they can plan, operate and maintain an ever-improving intelligent transportation network. Included are the geospatial location of these assets, the graphic representation of these networks and their geospatial context in map form. This BIM solution includes workflows to build and manage infrastructure models,

analyse current working conditions of the infrastructure, plan infrastructure improvements and plan future growth - all the components necessary for effective railway and roadway asset management. BIM data provides the ability to collaborate and distribute geospatially related data. BIM application provides the technology framework needed for cost-effective and efficient communication involving geospatially related information.

2.3.8 Transportation Management System

Planning, executing, monitoring and taking corrective action across the entire transportation lifecycle is critical in today's complex and constrained transportation environment. This is why manufacturers, retailers and logistics service providers choose BIM Transportation Manager to effectively manage their high-volume, sophisticated transportation networks. From order management through customer service and financial settlement, BIM Manager supports the entire transportation

lifecycle. It allows users to quickly create and modify least-cost shipment plans and loads that maximise capacity utilisation.

Benefits from using BIM are overall cost reduction resulting from transportation optimisation, improved service levels and customer satisfaction, reduction in damage-in-transit losses and the ability to enhance the reliability and efficiency of the distribution network.

2.3.9 Traffic Volume Simulation

The performance measures generated by such BIM models, as well as their visualisation capabilities, will allow detailed operational analyses of travel

corridors in the area and assist in determining the potential effectiveness of transportation projects and access management practices.

2.3.10 GIS Asset Tracking

The BIM helps you monitor the location and movement of objects in real time. Objects that can transmit their geographic location via Global Positioning Systems (GPS) or similar technologies can be dynamically tracked on a display map that can be shared via the Internet or intranet.

Analytical features enable users to trigger an action based on an object's location relative to other geographic features, such as triggering an alert when a vehicle or cargo moves out of its service area.

BIM data support a diverse range of asset tracking applications such as

- **Personnel tracking:** tracking the location and status of mobile teams, drivers, or repair crews

- **Mobile asset tracking:** real-time location and status of vehicles, trains, trucks, ships, airplanes, and cargo containers
- **Traffic control:** traffic flow analysis and real-time monitoring of traffic flow

With automatic vehicle location (AVL) tracking and a GIS-based display, dispatchers can visually relate mobile unit locations to destination locations. When live information or video feeds are incorporated into the map-based display, dispatchers can also keep an eye on the latest weather and traffic developments.

2.3.11 Water Mitigation and Planning

BIM can play an important role in assessing the risk of communities to flood events and the development and implementation of appropriate mitigation measures to reduce the severity and frequency of flooding. The

most visible approach for flood mitigation involves structural measures which include flood mitigation dams, retarding basins, channel levees and channel improvements.

3 BIM model development

3.1 Transportation (main road, highway and railway)

The transportation model of CityGML is a multi-functional, multi-scale model focusing on thematic and functional as well as on geometrical/topological aspects. Transportation features are represented as a linear network in LOD0. Starting from LOD1, all transportation features are geometrically described by 3D surfaces. The area modelling of transportation features allows for the application of geometric route planning algorithms. This can be useful to determine restrictions and manoeuvres required along a transportation route. This information can also be employed for trajectory planning of mobile robots in the real world or the automatic

placement of avatars (virtual people) or vehicle models in 3D visualisations and training simulators. In CityGML, the main class is *TransportationComplex*, which represents, for example, a road, a track, a railway, or a square. Fig. 2 illustrates the four different thematic classes. A *TransportationComplex* is composed of the parts *TrafficArea* and *AuxiliaryTrafficArea*. Fig. 3 depicts an example for a LOD2 *TransportationComplex* configuration within a virtual 3D city model. The Road consists of several *TrafficAreas* for the sidewalks, road lanes, parking lots, and of *AuxiliaryTrafficAreas* below the raised flower beds.

Fig. 2: Representations of *TransportationComplex* (from left to right: examples of road, track, rail, and square) (source: Rheinmetall Defence Electronics).

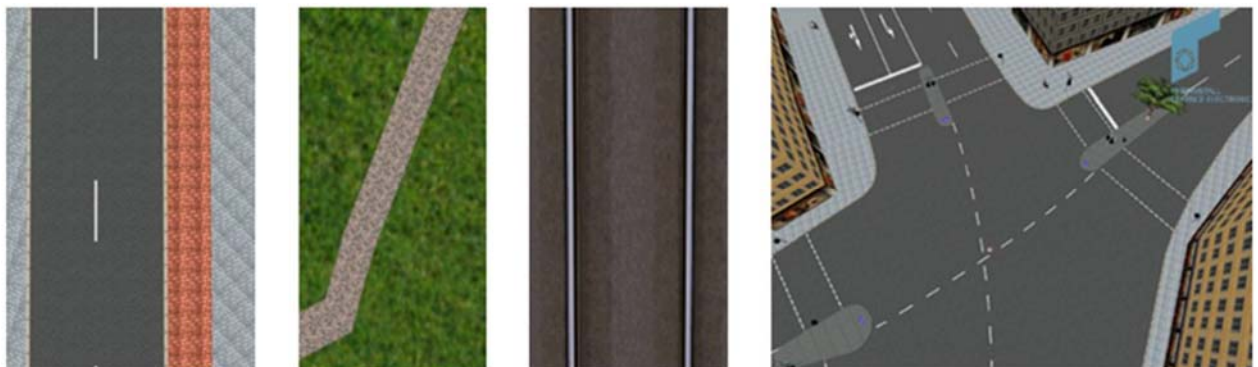
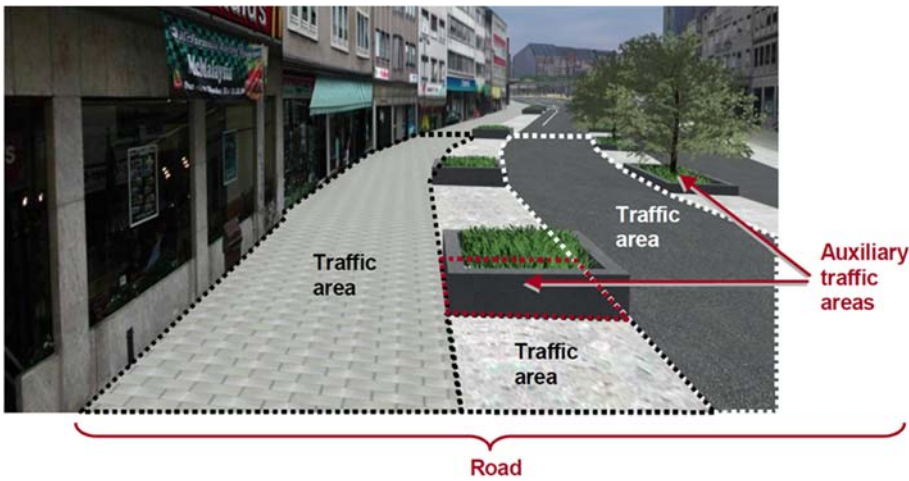


Fig. 3: Example for the representation of a *TransportationComplex* in LOD2 in CityGML: a road, which is the aggregation of *TrafficAreas* and *AuxiliaryTrafficAreas* (source: City of Solingen, IGG Uni Bonn).



In the coarsest LOD0 the *TransportationComplexes* are modelled by line objects establishing a linear network. On this abstract level, path finding algorithms or similar analyses can be executed. It also can be used to generate schematic drawings and visualisations of the transport network. Since this abstract definition of a transportation network does not contain explicit descriptions of the transportation objects, it may be a task of the viewer application to generate the graphical visualisation, for example by using a library with style-definitions (width, colour resp. texture) for each transportation object. Starting from LOD1 a *TransportationComplex* provides an explicit surface geometry, reflecting the actual shape of the object, not

just its centerline. In LOD2 to LOD4, it is further subdivided thematically into *TrafficAreas*, which are used by transportation, such as cars, trains, public transport, airplanes, bicycles or pedestrians and in *AuxiliaryTrafficAreas*, which are of minor importance for transportation purposes, for example road markings, green spaces or flower tubs. The different representations of a *TransportationComplex* for each LOD are illustrated in Fig.4 and Fig.5.

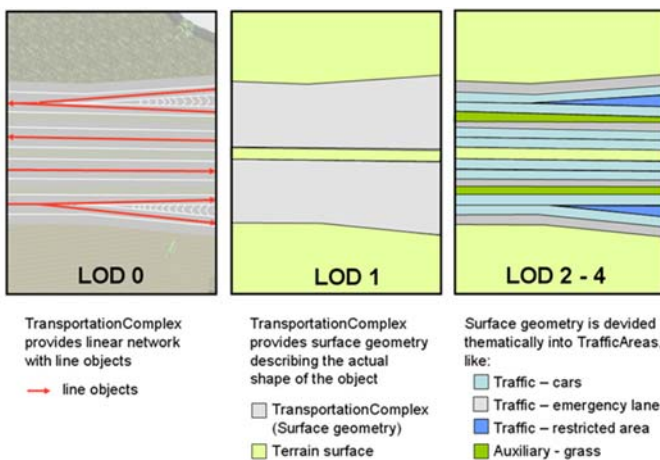


Fig. 4: *TransportationComplex* in LOD0, 1, and 2-4 (example shows part of a motorway) (source: Rheinmetall Defence Electronics).

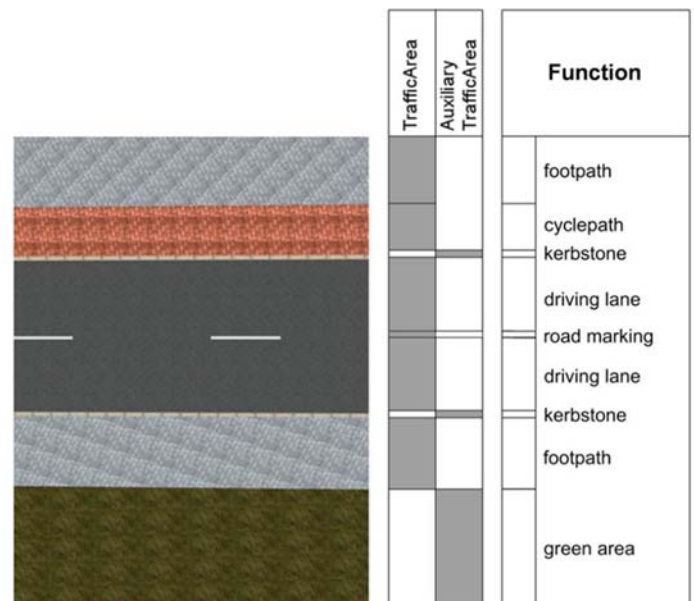


Fig. 5: *TransportationComplex* in LOD 2-4: representation of a road with a complex cross-section profile (example shows urban road) (source: Rheinmetall Defence Electronics).

3.2 Bridge model

The bridge model allows for the representation of the thematic, spatial and visual aspects of bridges and bridge parts in four levels of detail, LOD 1 – 4 (as shown in Fig. 6). In analogy to the building model, the semantical as well as the geometrical richness increases from LOD1 (blocks model) to LOD3 (architectural model). Interior structures

like rooms are dedicated to LOD4. To cover the case of bridge models where the topology does not satisfy the properties of a solid (essentially water tightness), a multi surface representation is allowed. The line where the bridge touches the terrain surface is represented by a Terrain Intersection Curve, which is provided for each LOD.

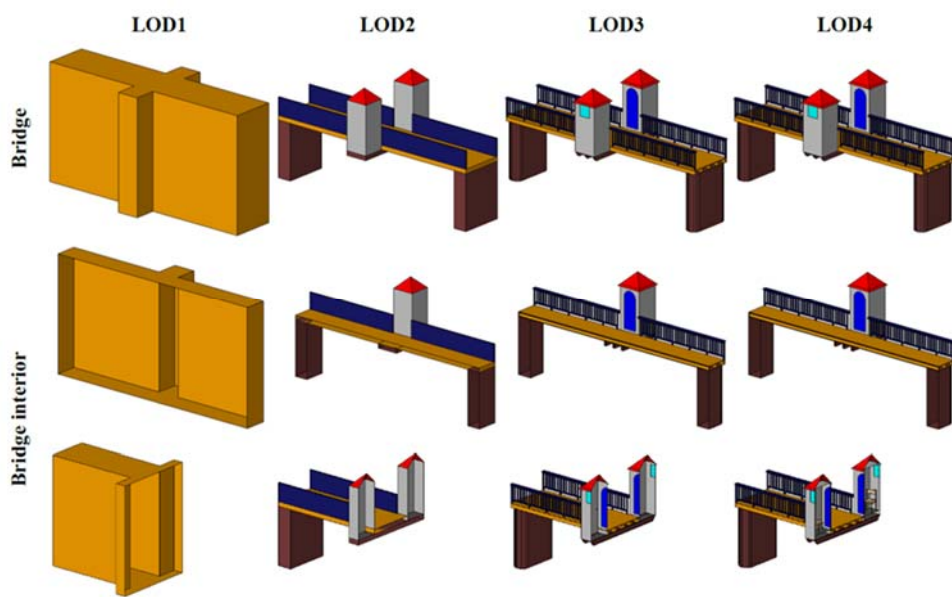


Fig. 6: Bridge model in LOD1 – LOD4. (source: Karlsruhe Institute of Technology (KIT))

3.3 Tunnel model

The tunnel model supports the representation of thematic and spatial aspects of tunnels and tunnel parts in four levels of detail, LOD1 to LOD4 (as

shown in Fig. 7). The thematic classification of tunnel surfaces is illustrated in Fig. 8 for different types of tunnel cross sections.

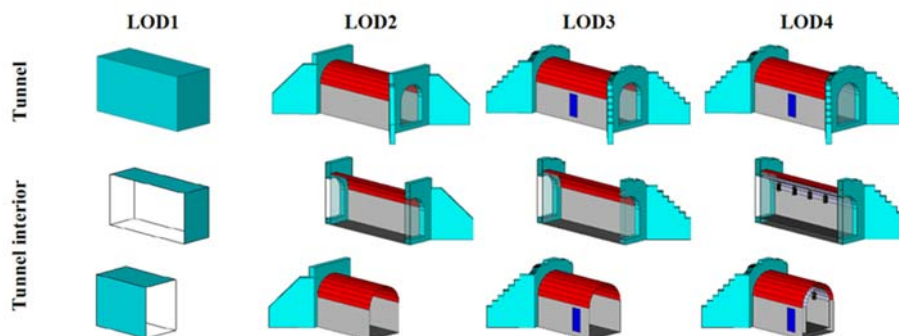


Fig. 7: Tunnel model in LOD1 – LOD4 (source: Karlsruhe Institute of Technology (KIT)).

In LOD1, a tunnel model consists of a geometric representation of the tunnel volume. Optionally, Terrain Intersection Curve can be specified. These curves denote the exact position, where the terrain touches the 3D object.

The geometric representation is refined in LOD2 by additional Surfaces and Curves. In LOD2 and higher LODs the outer structure of a tunnel can also be differentiated semantically by the Boundary Surface and Tunnel Installation. A Boundary Surface is a part of the tunnel's exterior shell with a special function like wall, roof, ground plate, outer floor, outer ceiling. The Tunnel Installation is used for tunnel elements like outer stairs, strongly affecting the outer appearance of a tunnel.

In LOD3, the openings objects (doors and windows) can be represented as thematic objects.

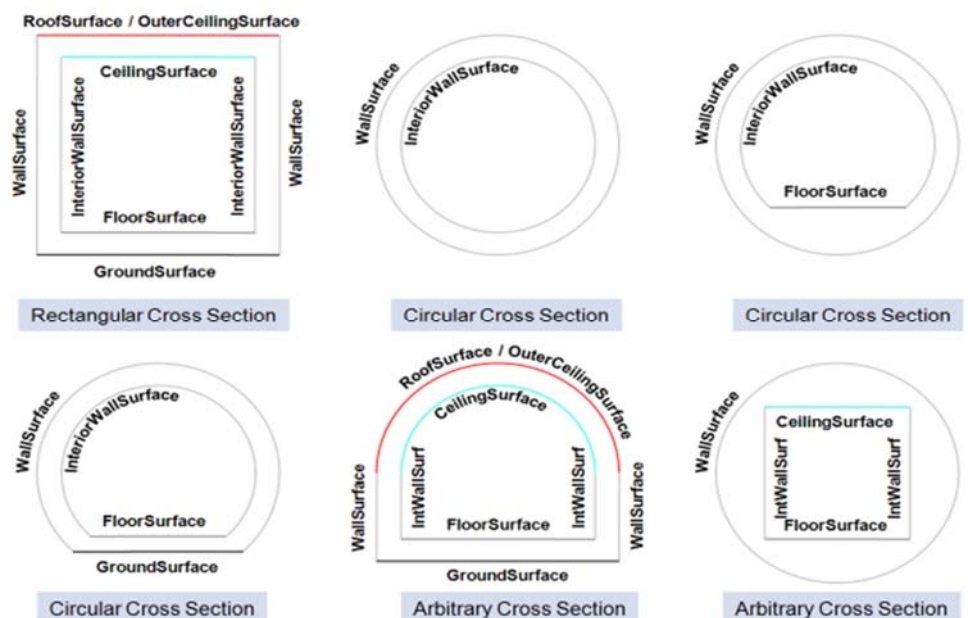
In LOD4, the highest level of resolution, also the interior of a tunnel, composed of several Hollow Spaces, is represented in the tunnel model. This enlargement allows a virtual accessibility of tunnels, e.g. for driving through a tunnel, for

simulating disaster management or for presenting the light illumination within a tunnel. The aggregation of Hollow Spaces according to arbitrary, user defined criteria (e.g. for defining the hollow spaces corresponding to horizontal or vertical sections) is achieved by employing the general grouping concept provided by CityGML. A Hollow Space may have the attributes class, function and usage. The class attribute allows a general classification of hollow spaces, e.g. commercial or private rooms, and occurs only once. The function attribute is intended to express the main purpose of the hollow space, e.g. control area, installation space, and storage space. The attribute usage can be used if the way the object is actually used differs from the function. Both attributes can occur multiple times.

Spanning the different levels of detail, the tunnel model differs in the complexity and granularity of the geometric representation and the thematic structuring of the model into components with a special semantic meaning. This is illustrated in Fig. 8, showing the same tunnel in four different LODs.



Fig. 8: Examples for the use of boundary surfaces for tunnels with different cross sections. *WallSurface*, *RoofSurface*, *GroundSurface*, *OuterCeilingSurface* and *OuterFloorSurface* are available in LOD2-4, whereas *InteriorWallSurface*, *FloorSurface* and *CeilingSurface* may only be used in LOD4 to model the interior boundary surfaces of a hollow space. (source: OGC CityGML Encoding Standard)



3.4 LOD5 and LOD6 development

LOD0-LOD4 which comes from CityGML standard is useful in infrastructure planning and design stages. However, it is not suitable in construction and operation and maintenance stages. From the lifecycle management perspective, it is necessary to develop the further LOD, such as LOD5 for construction stage and LOD6 for operation and maintenance stage. LOD5 and LOD6 are developed based on Infrastructure Model Element level. Figs 9-12 show the detailed model element for four different types of infrastructure projects.

LOD5: The Infrastructure Model Element is graphically represented within the Model as a specific system, object or assembly in terms of size, shape, location, quantity, and orientation with detailing, fabrication, assembly, and installation information. Non-graphic information may also be attached to the Model Element.

LOD6: The Infrastructure Model Element is a field verified representation in terms of size, shape, location, quantity, and orientation. Non-graphic information may also be attached to the Model Elements.

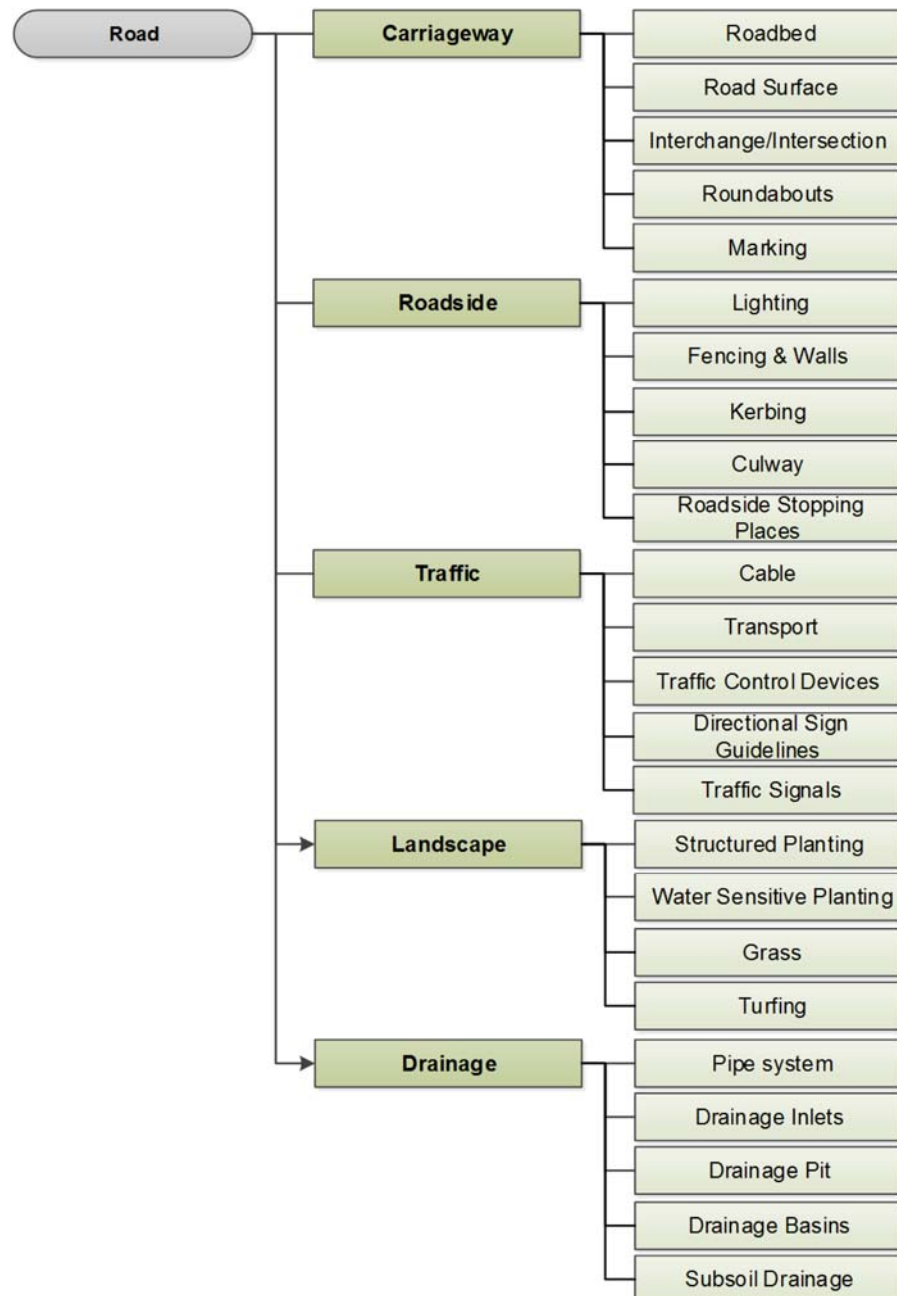


Fig. 9: Model elements for road

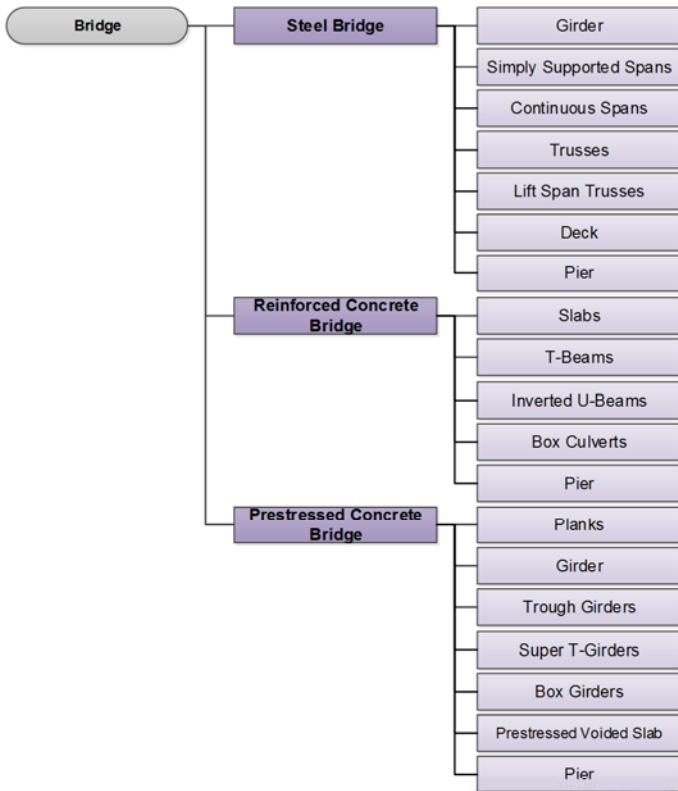


Fig. 10: Model elements for bridge

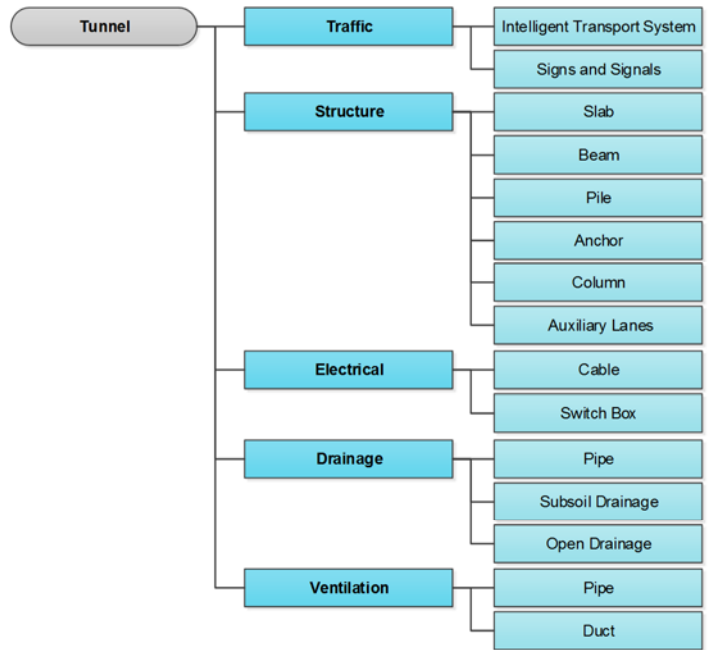


Fig. 11: Model elements for tunnel

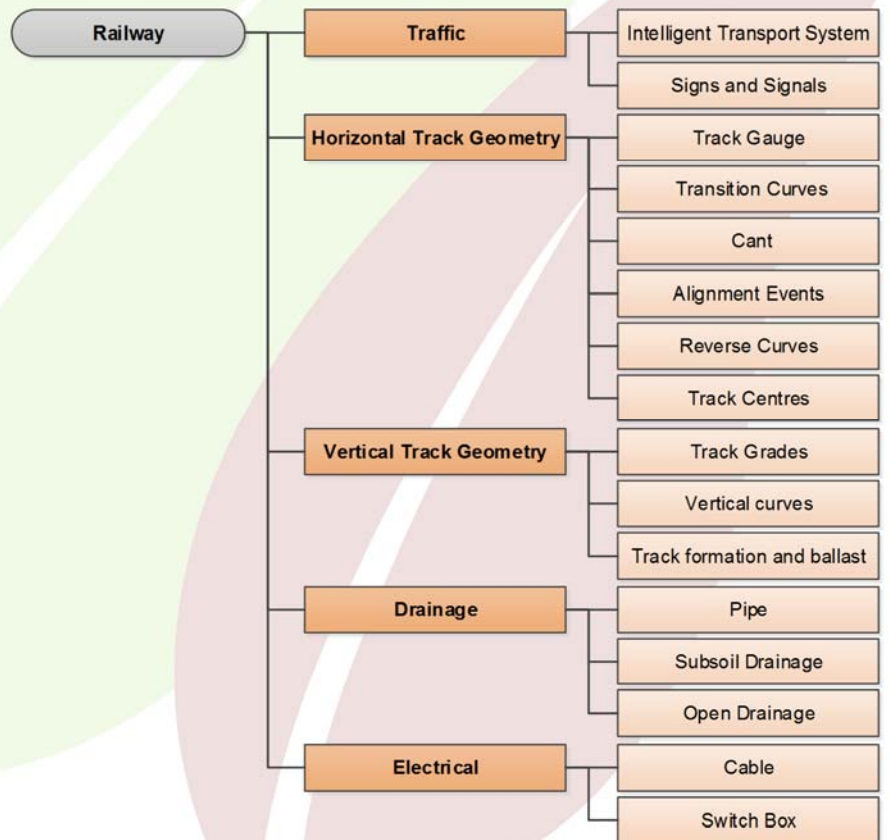


Fig. 12: Model elements for railway



4 BIM model management

Managing the development of the BIM model requires skills that are similar to managing the real thing. BIM production is done by people who understand computer technology but do not necessarily understand how to manage the workflow into a BIM model from multiple sources. In order to improve the quality of BIM models, BIM model management requires setting modelling guidelines, BIM roles and responsibilities, and BIM model assessment.

4.1 Modelling guidelines

4.1.1 BIM Element Modelling

In general, each element will be modelled according to its size, shape, location, orientation and quantity. At the early stages of the project,

element properties are more generic and approximate, but become more specific with increases in accuracy as the project progresses.

4.1.2 Model Orientation and Site Configuration

The origin point for the project should be clearly defined and drawn in the real orientation or spatial coordinate system

and with reference to Australia Standard Datum.

4.1.3 Model Division and Structure

Depending on the size of the building and / or the phasing for the project, it may be necessary to divide the model

into separate building, zones and levels. This should be agreed and documented as early as possible.

4.1.4 Revision Management

The model will evolve rapidly during the project stages. Changes should be tracked and catalogued, especially when the model creation task is divided into a few smaller packages and handled by different people.

There are various software mechanisms to assist BIM users to manage and monitor design changes. BIM users

should work with their respective BIM vendor to familiarise themselves with the use of these software mechanisms so that design changes can be managed more effectively. The BIM coordinator for each discipline could play the role of maintaining a register to record the latest information incorporated in the model.

4.2 BIM model assessment and quality control

Project teams should determine and document their overall strategy for quality control of the model. To ensure model quality in every project phase and before information exchanges, procedures must be defined and implemented. Each BIM created during the lifecycle of a project must be pre-planned considering model content, level of detail, format and the party responsible for updates and distribution

of the model and data to various parties. Each party contributing to the BIM model should have a responsible person to coordinate the model. This person, as part of the BIM team, should participate in all major BIM activities as required by the team. They should be responsible for addressing issues that might arise with keeping the model and data updated, accurate, and comprehensive.

Quality control of deliverables must be accomplished at each major BIM activity such as design reviews, coordination meetings or milestones. The standard of data quality should be established in the planning process and agreed upon by the team. If a deliverable does not meet the team's standards, the reason why the deliverable is lacking should be further investigated and prevented in the future. The deliverable needs to comply with standards required by the owner and agreed upon by the project team.

Each project team member should be responsible for performing quality control checks of their design, dataset and model properties before submitting their deliverables. Documentation confirming that a quality check was performed can be part of each submittal or BIM report. The BIM Manager should be the one to confirm quality of the model after the revisions were made.

The following quality control checks should be considered when determining a plan for quality control:

Visual Check: Ensure there are no unintended model components and the design intent has been followed by using navigation software

Interference Check: Detect problems in the model where two building components are clashing by a Conflict Detection software

Standards Check: Ensure that the model is to the standards agreed upon by the team.

Element Validation: Ensure that the dataset has no undefined or incorrectly defined elements

Each party should designate a responsible party to make sure that the agreed upon process for quality control of models and data has been followed before accepting submittals and model revisions.



4.2.1 Model Division and Structure

The team must identify the methods to ensure model accuracy and comprehensiveness. After agreeing on collaboration procedures and technology infrastructure needs, the planning team should reach consensus on how the model is created, organised, communicated and controlled. Items to consider include:

- Defining a file naming structure for all designers, contractor, subcontractors, and other project members
- Describing and producing a diagram how the models will be separated (e.g. by building, by floors, by zones, by areas, and/or by disciplines)
- Describing the measurement system (imperial or metric) and coordinate system (geo-referenced / origin point) to be used to allow for easier model integration
- Identifying and agreeing upon items such as the BIM and CAD standards, content reference information, and the version of IFC, etc.

4.2.2 Model Delivery Schedule for Information Exchange

Determine the schedule for information exchange between parties. Information exchanges should be analysed in earlier steps; however it is helpful to document them all in one place. Information that should be considered includes:

- Information exchange name (should be drawn from step 3 of the planning process)
- Information exchange sender
- Information exchange receiver
- One-time or frequency (is this a one – time or periodic exchange? If periodic, how often?)
- Start and due dates
- Model file type
- Software used to create file
- Native file type
- File exchange types (receiver file type)



4.3 Electronic communication procedures

Establish communication protocol with all project team members. Electronic communication with stakeholders can be created, uploaded, sent out and archived through a collaborative project management system. Save copies of all project related communication for

safekeeping and future reference.

Document management (file folder structure, permissions and access, folder maintenance, folder notifications, and file naming convention) should also be resolved and defined.

4.4 Interactive workspace

The project team should consider the physical environment it will need throughout the lifecycle of the project to accommodate the necessary collaboration, communication, and reviews that will improve the BIM Plan decision making process. Describe how the project team will be located.

Consider questions like “will the team be

co-located?” If so, where is the location and what will be in that space? Will there be a BIM Trailer? If yes, where will it be located and what will be in the space such as computers, projectors, tables, table configuration? Include any necessary information about workspaces on the project.

4.5 Technology infrastructure needs

The team should determine the requirements for hardware, software platforms, software licenses, networks, and modelling content for the project.

Software

Teams and organisations need to determine which software platforms and version of that software is necessary to perform the BIM Uses that were selected during the planning process. It is important to agree upon a software platform early in the project to help remedy possible interoperability issues. File formats for information transfer should have already been agreed upon during the information exchange planning step. Additionally, the team should agree upon a process for changing or upgrading software platforms and versions, so that a party does not create an issue where a model is no longer interoperable with other parties.

There are two kinds of BIM software: authoring software and simulation software. As the technology matures single software packages may be used that contain both elements.

Common authoring software platforms include Autodesk Revit, Bentley AECOSim, ArchiCAD, TEKLA, CATIA, Sketchup, Digital Project, Rino and so on. Simulation Software platforms include 4D, 5D and nD simulation software, such as Navisworks, ConstructSim, Vico, RIB, and DELMIA.

BIM simulation software is potentially revolutionary for construction management and contractors in particular. This software takes the model

made by the authoring software and attaches cost, scheduling and other information to it thus creating a tool for achieving improved project delivery.

See the detailed list of existing BIM tools in **Appendix B.**

Computers / Hardware

Understanding hardware specifications becomes valuable once information begins to be shared between several disciplines or organisations. It also becomes valuable to ensure that the downstream hardware is not less powerful than the hardware used to create the information. In order to

ensure that this does not happen, choose the hardware that is in the highest demand and most appropriate for the majority of BIM Uses.

Modelling Content and Reference Information

The project and reference information, such as Modelling families, workspaces, and databases, must be considered to ensure that the project parties will use consistent standards.

4.6 Revision management

The model will evolve rapidly during the project stages. Changes should be tracked and catalogued, especially when the model creation task is divided into a few smaller packages and handled by different people.

There are various software mechanisms to assist BIM users to manage and monitor design

changes. BIM users should work with their respective BIM vendor to familiarise themselves with the use of these software mechanisms so that design changes can be managed more effectively. The BIM coordinator for each discipline could play the role of maintaining a register to record the latest information incorporated in the model.



5 BIM collaboration

5.1 BIM roles and responsibilities

5.1.1 The BIM Project Manager

BIM project should assign an individual to the role of BIM project manager. This individual should have the appropriate level of relevant BIM experience required for the project complexity and acquisition delivery strategy. In general, responsibilities should include the following:

- Negotiating, developing and enforcing the BIM protocol
- Liaising with each contributing BIM team
- Coordinating BIM use on the project, including quality control, access rights and security
- Helping resolve design issues and change control procedure
- Managing and distributing digital outputs, data transmission, and archiving.

5.1.2 BIM Coordinator

All major technical disciplines/trades should assign an individual to the role of lead BIM technician to coordinate their work with the entire Design/Construction Team. These individuals should have the relevant BIM experience required by the complexity of the project and should have, as a minimum, the following responsibilities for their discipline:

- Coordinating technical discipline BIM development, standards, data requirements, etc. as required with the design team BIM manager
- Leading the technical discipline team BIM in its documentation and analysis efforts
- Coordinating clash detection and resolution activities
- Coordinating internal and external BIM training as required
- Coordinating trade items into the design BIM (depending on acquisition).

5.1.3 Design BIM Manager

The design team should assign an individual to the role of design team BIM manager. The individual should have sufficient BIM experience for the size and complexity of the project and should have relevant proficiency in the proposed BIM authoring and coordination software. The individual should serve as the main point of contact with the BIM project manager and the design team for BIM related issues. In general, responsibilities should include the following:

- Ensuring development and compliance with the approved design for BIM
- Developing, coordinating, publishing the design plan and verifying that all necessary configurations required for the seamless integration of design and construction model information have been implemented
- Coordinating team file management
- Coordinating the setup of shared file server with design team IT staff. This should include interfacing with design team IT staff to set up web portal, permissions, etc.
- Assembling composite design models for coordination meetings
- Facilitating use of composite design models in design coordination/clash detection meetings and providing detection reports based on the identification and resolution of all hard and soft collisions
- Ensuring that BIM is used appropriately to test design requirements/criteria for functionality
- Correctly classifying all spaces and equipment in the model to ensure direct comparison with the program for design and downstream use for facility management as required
- Liaising with design team, BIM and IT managers to ensure software is installed and operating properly
- Facilitating BIM technical meetings with discipline lead BIM coordinators
- Determining the project BIM geo-reference point, and ensuring all technical discipline models are properly referenced to the point
- Liaising with the client's facilities management department to determine specific data and file exchange requirements
- Ensuring that the design deliverables specified in the contract are provided in conformance with the formats specified
- Ensuring information for facility management (e.g. COBie), as required by the BIM project brief, is provided for the contractor at nominated submittal milestones
- Ensuring proper BIM derived 2D information for paper printing is provided as required and that it conforms to the CAD/Drawing standards
- Coordinating with the contractor to assure the creation of proper BIM final deliverables.
- Aligning the requirements and deliverables of different design team members irrespective of their contractual lineage, e.g. IPD, EPC, DB

5.1.4 Construction BIM Manager

The construction team should assign an individual to the role of construction team BIM manager. This individual should have the appropriate level of relevant BIM experience required for the project complexity and acquisition delivery strategy. In general, responsibilities should include the following:

- Taking overall responsibility for the construction BIM model creation and information developed during construction
- Establishing software protocols for the construction team for efficient delivery of project
- Acting as the main point of contact for BIM and related issues between the construction team, subcontractors, the client, the design team and others as required
- Where a contractor's BIM Coordination Room is required by the project BIM brief, providing specifications for it to the client for approval. Ensuring that the construction team has necessary hardware and BIM software properly installed and accessible for project use
- Where 4D BIM is required, ensuring construction sequencing and scheduling activities are integrated with the construction BIM
- Facilitating use of composite trade models in construction coordination/clash detection meetings and providing detection reports based on the identification and resolution of all hard and soft collisions
- Communicating with the design team, coordinating the data extraction sets required by the construction trades and ensuring that these requests are met
- Coordinating with the design team to facilitate the documentation of design changes in the field and updating of the BIM in a timely manner
- Prior to approval and installation, working with Lead Fabrication Modellers to integrate 3D fabrication models with the updated design model to ensure compliance with design intent
- Coordinating update of as-built conditions in the final model deliverable
- Coordinating with design team and commissioning agent to ensure facility management (e.g. COBie) information, where required, is complete

Table 2: Overview of responsibilities for BIM roles

Defined Role	Responsibility in BIM Implementation	BIM Responsibility
Project Manager	Manages and coordinates project execution and BIM to meet procurement strategy and cost containment.	Oversight.
Design Team Project Manager	Team manager and coordinator, BIM Manage Plan.	Coordination & Review
(Design Team or Construction) BIM Manager	Coordinate BIM use on project, determine schedule of use, sharing activities, quality control, modelling responsibilities and documentation in BIM Manage Plan.	Oversight, Management Execution and Model Exchange.
Lead BIM Coordinator	Assist BIM Manager.	Implementing BIM Manager instructions with (Design or Construction) Team. Representing BIM Manager.
Survey and Mapping Team	Engineering – formulate with BIM Manager. Map BIM use for Surveying and mapping. Identify tools.	Data Development. Modelling and Model Exchange.
Transport Planning Team	Engineering – formulate with BIM Manager. Map BIM use for Transport Planning. Identify tools.	Data Development. Modelling and Model Exchange.
Bridge Design Team	Engineering – formulate with BIM Manager. Map BIM use for Bridge Design. Identify tools.	Data Development. Modelling and Model Exchange.
Tunnel Design Team	Engineering – formulate with BIM Manager. Map BIM use for Tunnel Design. Identify tools.	Data Development. Modelling and Model Exchange.
Landscape Design Team	Engineering – formulate with BIM Manager. Map BIM use for Landscape Design. Identify tools.	Data Development. Modelling and Model Exchange.
Drainage Design Team	Engineering – formulate with BIM Manager. Map BIM use for Drainage Design. Identify tools.	Data Development, Modelling and Model Exchange.
Traffic Design Team	Engineering – formulate with BIM Manager. Map BIM use for traffic design. Identify tools.	Data Development Review and use of model.
Building Users Group	Determine facility functional issues to be modelled and tested.	Development of critical building use issues and inputs for testing, and their review.
Commissioning Agent	Support. Provide architectural, engineering, equipment compliance reports produced in the specified exchange format.	Data Development Review and use of model.
BIM Modelling Application Expert	Support BIM Manager on application specific content, issues.	Modelling and Data Integration.
Quantity Surveyor/Cost Planner	Support alignment of project procurement to BIM development and cost containment strategies.	Data development and integration. Use of model.
Contractor	Receive or help create BIM for constructability and handover for field use. Determine interference checking responsibility.	Use of model, Review, Model Exchange.
Subcontractor and/or Fabricator (as appropriate)	Off-site Fabrication – formulate with BIM Manager and designer. Map BIM use for fabrication and shop drawing design. Determine BIM use for simulations of maintenance space analysis and documentation. Identify tools.	Use of model, Modelling and Integration.

5.2 Individual discipline modelling

At this stage each design discipline will create its model according to the agreed deliverables as stated above. The model data is stored in and worked on, by the modelling team of each respective design discipline and has not yet

been checked and verified for use outside of the team. To ensure modelling quality, Model Authors should set up and follow a minimum standard of modelling requirements during BIM project implementation.

5.3 Cross-disciplinary model design

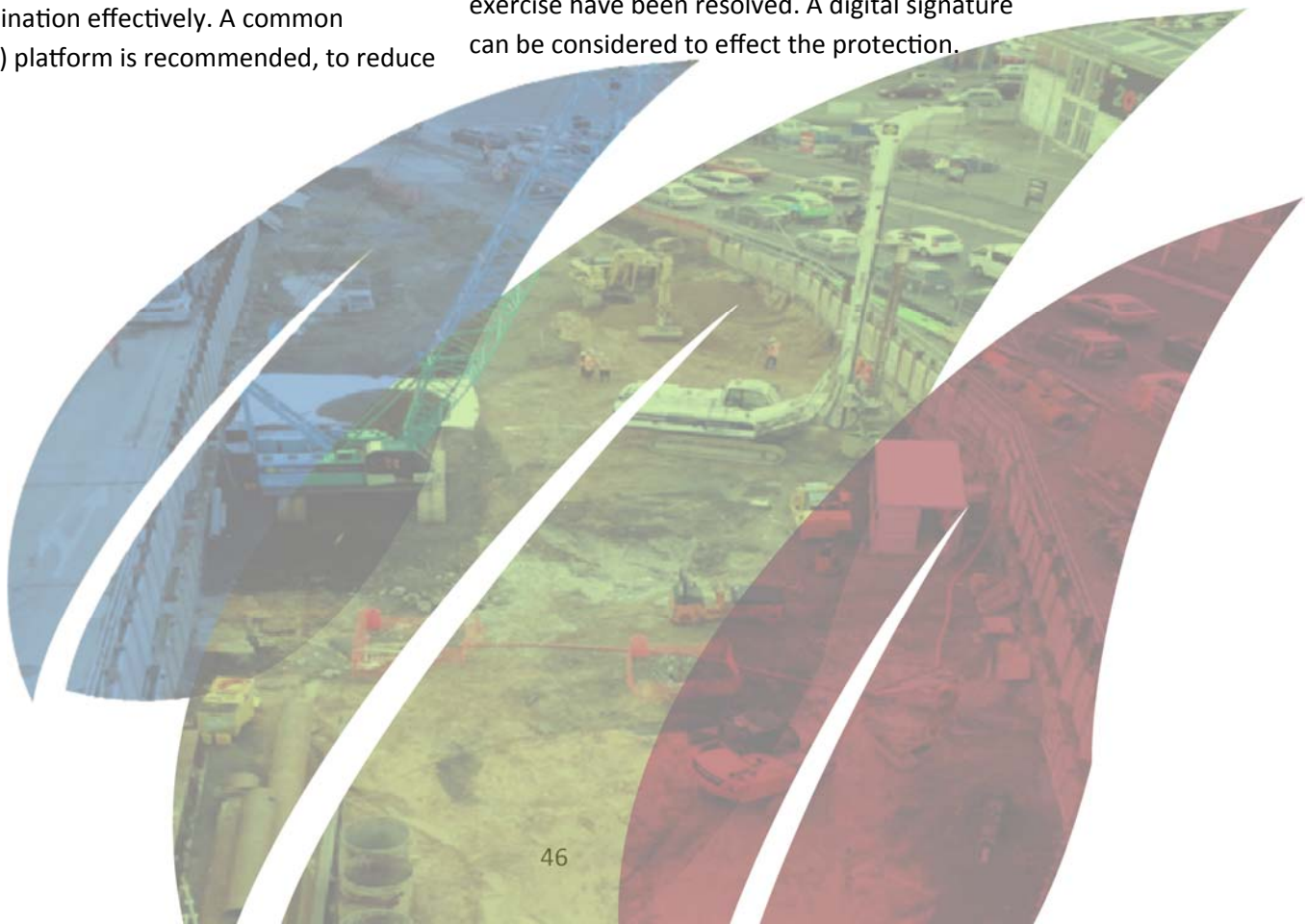
Project members should share their models with other project members at regular intervals for reference when they are developing their own single-discipline model. At certain milestones, models from different disciplines should be subject to various coordination processes, allowing involved parties to resolve potential conflicts upfront and avoid costly abortive works and delays at the construction stage.

Prior to sharing, the data should be checked, approved and validated as “fit for coordination”. The project team could leverage on the available software solutions to perform the coordination effectively. A common (software) platform is recommended, to reduce

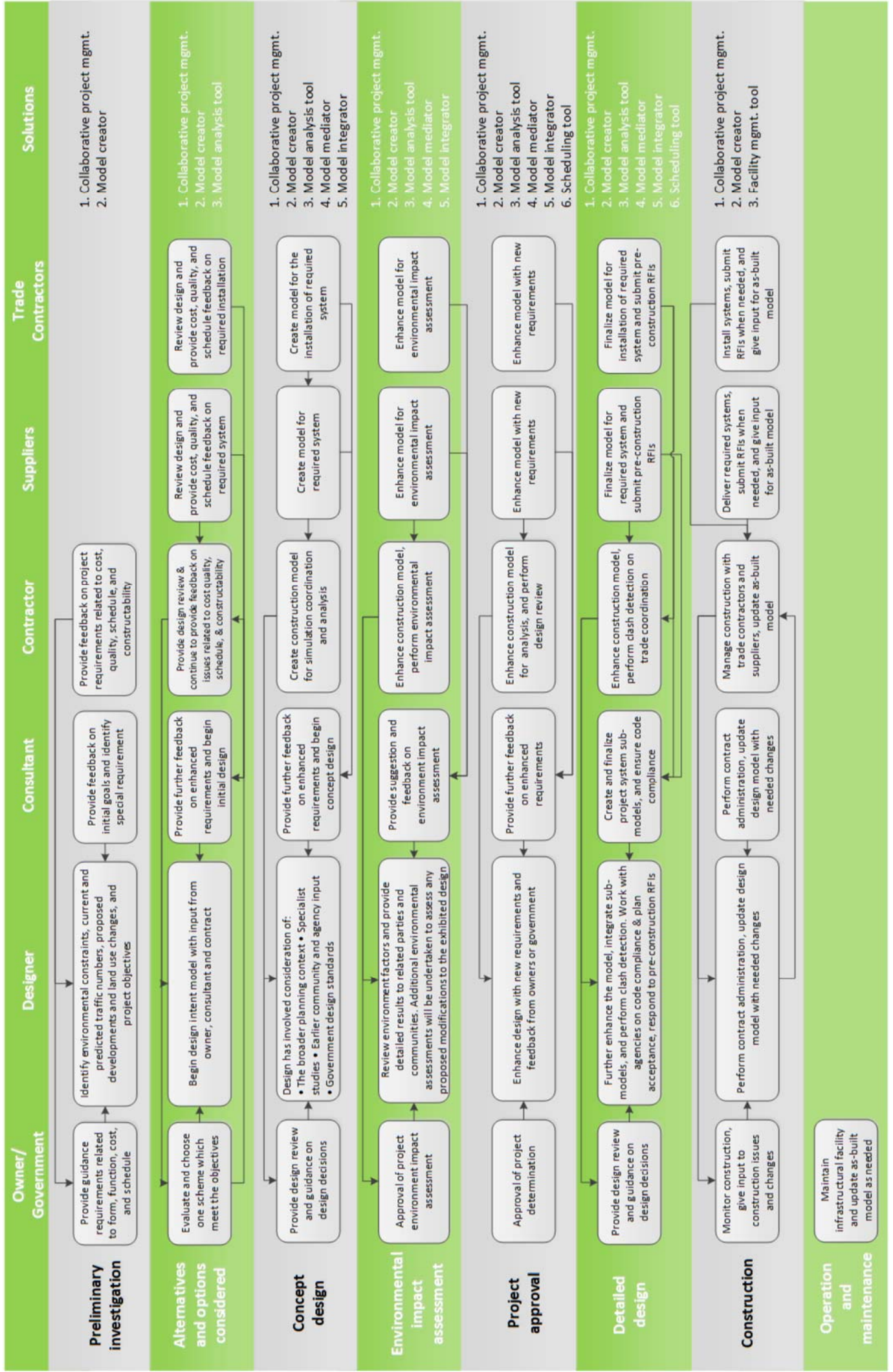
possibilities of data loss or errors when sharing different models. Issues that arose from the coordination should be documented and followed up.

Discrepancies discovered during the coordination process should be recorded, managed, and communicated to relevant model owners through coordination reports, including any specific location of interferences and suggested resolutions.

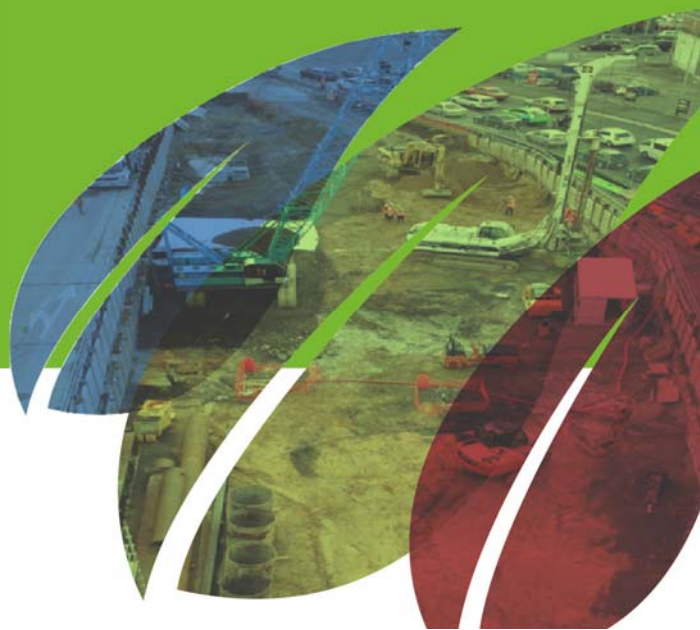
It is recommended that a revised version of the model should be frozen and signed-off after the issues identified during the coordination exercise have been resolved. A digital signature can be considered to effect the protection.



Example: Cross-disciplinary model design in a road project



6 BIM relevant issues



6.1 Different BIM models

Ideally, a construction project would utilise a single BIM model used by designers, contractors, subcontractors and fabricators for all purposes. Each party could access the model at will, adding content that all others could immediately utilise. The reality is that for many years there will rarely be a single BIM model. The architect may have its design model, each engineer may have an analysis model for its discipline, the contractor may have a construction simulation model and the fabricator its shop drawing or fabrication model. Interoperability - the sharing of

information between these different models - is critical to the collaborative use of BIM, by assuring that each model consistently represents the same building. However, current technologies, and levels of BIM adoption, do not yet allow seamless coordination between different BIM models. The use of multiple models undermines the collaborative use of BIM and prevents project parties from reaping the full benefits of BIM's capabilities.

6.2 Duplication

Some firms may not be able to afford BIM and therefore traditional drawings will still have to be produced to manage the downward supply chain. It is also likely that smaller contractors will not have access to the digital BIM model on-site. Further, most authorities require traditional drawings for planning and building regulation approval. This causes

duplication and creates the potential for ambiguity. If, for example, the contractual documents are in 2D but the project is designed in a BIM model – which will take precedence?



6.3 Ownership

In most projects, ownership of the BIM model is likely to be retained by the owner of the building. However, ownership of the data contained within the BIM model itself is a separate issue. Such data is likely to be wide-ranging, and contributions will come from a variety of different participants. For example, there is likely to be design data, cost data, design processes, tables, databases and graphical information. Different laws will govern each of these rights. Enhanced regard to intellectual property provisions is especially important since the BIM model will not only show the results of patented processes and designs, the BIM will actually 'know' the building codes,

algorithms and applicable engineering principles. It is this information which the system applies to enable the model of the building to be manipulated and updated. Therefore design participants will be required to depart much more intellectual property on a BIM project than they are traditionally used to. The terms of any assignment or licensing of intellectual property rights will therefore be of great concern to all design participants. Increased integration and collaboration also means that there will be complex layers of intellectual property, provided by different design participants, which will be difficult to identify and reverse engineer.

6.4 Designer's liability exposure

In a collaborative BIM model many parties contribute to the design. Crucial details embedded in the design may be provided not by design professionals, but by specialty subcontractors or consultants. In addition, BIM software is designed to react to changes in the

model, by modifying elements of the design affected by a change. These circumstances increase the potential liability exposure of design professionals who use BIM collaboratively and risk assuming overall model responsibility.

6.5 Professional terms of engagement

Terms of engagement for all of the project team will need to be considered and drafted to reflect the collaborative nature of BIM and to ensure that responsibilities, duties and services are aligned. Communication and methods of working will need to be outlined to enable those who are not in a direct

contractual relationship to work together in order to deliver the project in the integrated and collaborative spirit required by BIM. Provisions on the input of data, limitation of liability and defining the role of any BIM 'model manager' will also be crucial.

6.6 Risk profile

The risk profile for construction projects and project participants will change with use of a BIM model and a collaborative, integrated approach. Measures will need to be taken to mitigate any increased areas of risk. This may require insurance, indemnities, changes to contracts and/or

changes to policies and procedures. A balance will need to be struck between the need for fluid collaboration between parties on the one hand and the need to precisely define responsibility to manage the changed risk profiles on the other.

6.7 Mindset and approach

BIM will completely change the way that designers approach the design process. The level of information contained within a BIM model requires collaboration between different participants at an early stage to establish the initial

framework and incorporate the level of detail required. More hours will be spent during the design and less in production.

6.8 Information technology

BIM places increased reliance upon information technology. With this reliance comes the need for specific precautions such as careful control of access rights and recording of audit trails. Technical support facilities, firewall limitations, bandwidth limits, corruption of data and compatibility issues are amongst the other concerns that need to

be considered. The BIM model will be the core of the project and just one error in it can be very costly. Unlike the traditional approach, with plans that can be checked against one another, BIM plans are generated from the model and reflect the same data. This may allow small miscalculations, which can later lead to big problems that are difficult to spot.

6.9 Cost

BIM models will require significant investment from those across the industry. There will be the direct cost of the software and hardware but also indirect costs such as training and

obtaining suitable bandwidth to handle BIM data exchange. Given the level of investment necessary, the industry will take a cost benefit analysis to decide on adoption.

6.10 Owner

Owners are likely to pay for the operation and management of the BIM, for example, appointing an information or BIM model manager. However, the

owner stands to benefit most financially from BIM usage with both construction and operational savings.



6.11 Designers

Designers will have to spend significant amounts on purchasing software, licences, hardware and training staff. There will also be costs incurred from obtaining insurance (with potentially high premiums given the collaborative nature of BIM and increased risk of

collective design). However, designers will benefit from advanced design features, such as clash detection and value engineering tools. BIM also has a proven track record as a marketing tool, which provides a clear commercial advantage in any bid process.

6.12 Contractors

In a collaborative BIM model many parties contribute to the design. Crucial details embedded in the design may be provided not by design professionals, but by specialty subcontractors or consultants. In addition, BIM software is designed to react to changes in the

model, by modifying elements of the design affected by a change. These circumstances increase the potential liability exposure of design professionals who use BIM collaboratively and risk assuming overall model responsibly.

6.13 Level of detail

Contractors are likely to want more detail included within the model so that clashes, delays and extensions of time will be avoided during construction. However, with more detail added during the design phase, design costs will increase and the model will become

more difficult to manage and operate. Determining the balance of detail, and how much reliance can be placed upon it, will therefore be a crucial issue to be negotiated between all project participants.

6.14 Contractual implications

Historically most contracts are bipartite agreements. BIM has the potential to substantially alter the relationships between parties and blend their roles and responsibility. Risks will need to be allocated rationally; based on the benefits a party will be receiving from BIM, the ability of the party to control the risks, and the ability to absorb risks through insurance or some other means. As parties journey along the path to fully integrated BIM, bilateral contracts, with BIM addendums or protocols, may become unsuitable and collaborative multiparty contracts could potentially become more appropriate. Payment mechanisms may also need to be changed to reflect the fact that BIM projects will become front loaded. Pain / gain mechanisms for collaborating participants may also be favoured. The contract will also have to define the status of the BIM model and deal with post handover matters such as lifecycle management and data capture.

6.15 Insurance / bond markets

Few insurance companies currently offer BIM related products. The rarity of BIM projects to date means that uncertainties remain about its benefits and risks. Insurers are likely to increasingly offer BIM insurance policies but until it is clear what risks are involved premiums are likely to be high. Uncertainty is also likely to impact upon the bond market until BIM becomes more commonplace.

7 Case Studies



7.1 Case Study **1**

Upgrade of Great Eastern Highway, Western Australia

7.1.1 Project Background

This case study describes the Great Eastern Highway (GEH) upgrade, which was delivered by the City East Alliance. The alliance partners were Main Roads

WA, Leighton Contractors and GHD as the designer. This is a major access route between the Perth Domestic Airport and the Graham Farmer Freeway.

7.1.2 Major Stakeholders

Main Roads WA - Project (client), City East Alliance (MRWA, GHD, Leighton Contractors and NRW), Swan River Trust,

Aboriginal Heritage, and European Heritage.

7.1.3 Project Description

The upgrade consisted of expanding 4.2km of the highway from four to six lanes between Kooyong Road and the Tonkin Highway. It also included the construction of a central median along the length of the upgraded section, upgrading major intersections to allow for turning movements, bus lanes, on-road cycling facilities and a continuous pedestrian path. The project aims to ease congestion along the highway by increasing its capacity by 70%, from 50,000 to 85,000 vehicles a day. It will also improve access to the airport and

surrounding areas, improve safety for local residents and other users of the highway, and deliver better facilities for pedestrians and cyclists. The upgrade also included two variable message sign boards, CCTV cameras at each of the major signalised intersections and a fibre backbone running the length of the median. These systems will be used by Main Roads WA Traffic Operations Centre to help manage traffic congestion.





7.1.4 BIM Tools

AutoCAD, AutoCAD Civil 3D, Navisworks, 12d and MX

7.1.5 BIM Technical Analysis (Pros)

BIM 3D, 4D and 5D modellings were adopted in the virtual design and construction of the project. In addition, other BIM uses were also applied in the project such as:

- Constructability Reviews
- Traffic Impact Simulations
- 3D Coordination
- Engineering Analysis
- Clash Detection
- Product Master Data
- Field Survey

7.1.6 BIM Technical Analysis (Cons)

The scope of project ended after construction and the maintenance was handled by another stakeholder. However, some areas of BIM uses could be improved and developed in the future during the construction stage, such as :

Additionally, there is a very strong level of interest to adopt other BIM uses during operation and maintenance of the project, such as:

- Field Design Changes
- Mobile Progress Claiming
- Site Logistics (JIT)
- Virtual Project Scheduling
- Work Zone Safety Planning
- Virtual Work Planning
- Virtual Cost Reporting
- Visual Progress Reporting
- Quality Issue Tracking and Reporting
- Product Inspection and Testing.
- Road Management
- Maintenance of Traffic
- Geospatial Issue Tracking
- Equipment Machine Control

7.1.7 Process and Benefits

The screen shot of the Web Viewer below (Fig. 13) shows the project can be viewed on screen and acted as the “single point of truth” during the project’s construction. The Viewer is available to the public over the web

to view the current and planned works and better understand what will be occurring in their neighbourhood as this project has impacted hundreds of land holders and business.

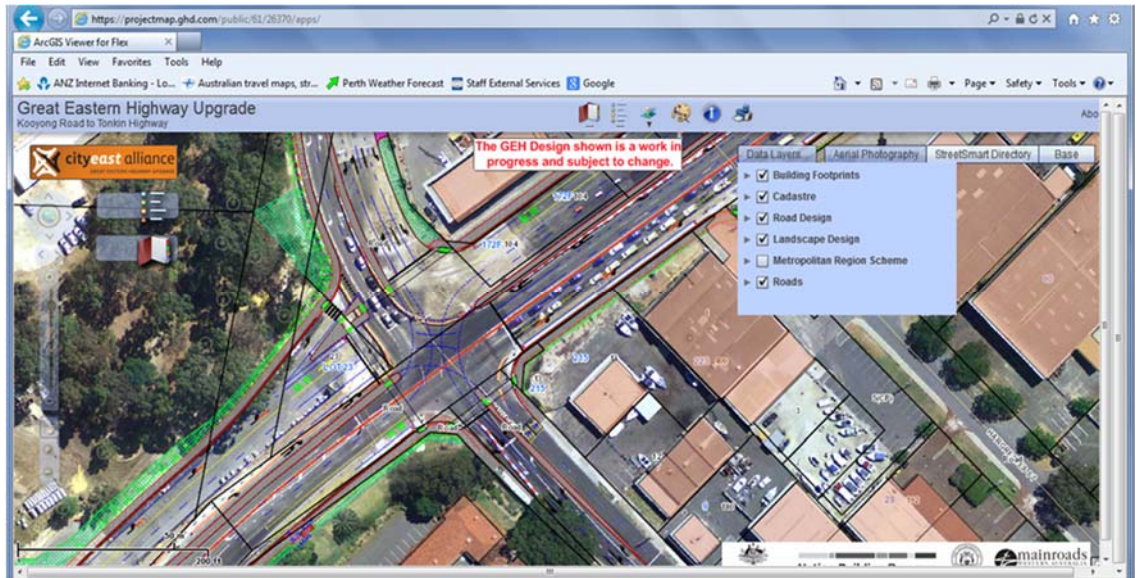


Fig. 13 Web-based Interface

The benefits in terms of accurate and current visualisation for Stakeholder Consultation are substantial. The project team have access via tablets and iPads to an enhanced Version containing additional layers of information.

It has been synchronised on a monthly basis with the 3D Navisworks model and updated utilising the GIS and Navisworks Data (Fig 14 below).

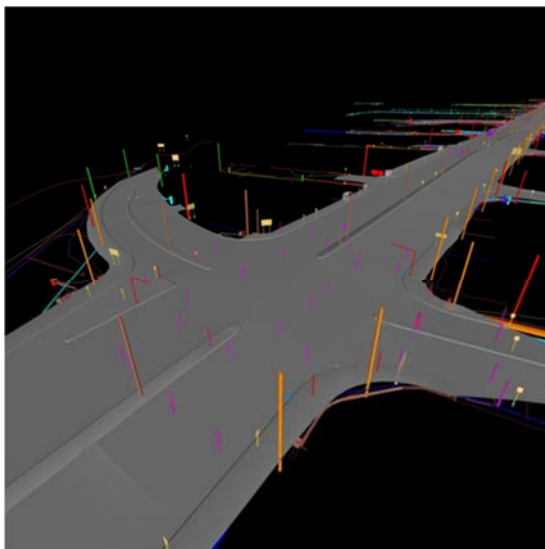
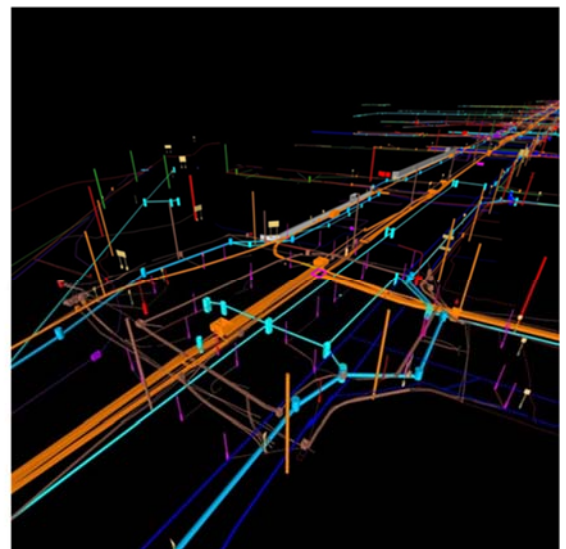


Fig. 14 Different level of Details in BIM



From the quality aspects, the construction engineers were aware of where they should not dig and the designer could physically see the space and obstructions to design around.

Fig. 15 illustrates the accurate information in the model compared to the as-built construction.

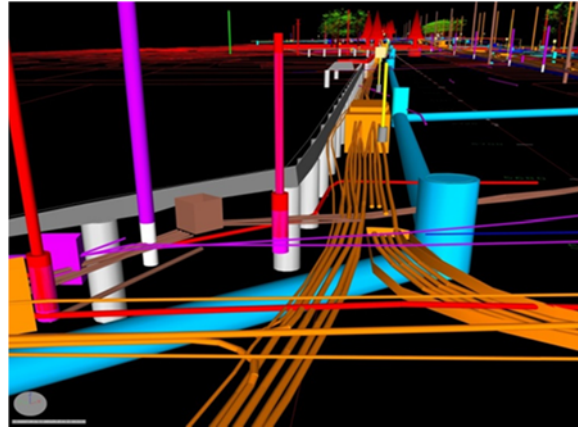


Fig. 15
Comparison
of as-built
versus as-
planned

7.1.8 Process Challenges

A few challenges were encountered in the project. These were:

- The limited project delivery timeframe required the construction of the new road before all utilities could be relocated. As such, critical construction activities such as earthworks cut and fill, retaining wall construction and street lighting installation had to occur in and around live services
- There were dense utility corridors, which were containing over 80km of existing cabling, pipe and conduit within the 4km project. They were required to be relocated
- Maintaining access to all land owners and businesses for the length of the project
- High initial investment and start-up cost was a significant concern to the management team
- Location of existing utilities and buried infrastructure

7.1.9 Conclusion

The project was completed successfully in terms of cost, time and quality of works by applying numerous BIM uses in the project. Some areas of BIM uses were highlighted for future use, particularly during the construction and operation stages.

Furthermore, it is worth noting that the construction cost on Great Eastern Highway for utility relocations alone was about \$8 million per kilometre, with reductions from the initial estimates of about \$2 million per kilometre attributable to efficiencies identified in the model.

The project has involved a total of 1.175 million man hours with 0 lost time injury (LTIFR =0). The project has achieved a national HSE Award for the Leighton Group.

Overall the project ran \$7 million under the targeted budget and 3 months ahead of the targeted completion date, of which the total saving contributed to by the model was \$24 million or equivalent to 14% of the total project cost of \$175 million.

7.2 Case Study 2

Moreton Bay Rail Project, Queensland

7.2.1 Project Summary

The *Queensland Transport and Main Roads State Planning Program* is based on analysis of current and future integrated passenger transport options. Investment decisions must take into account the challenges of distance in order to deliver quality transport networks for a growing population. Use of the *Regional Queensland Passenger Transport Network Plan* assists with the identification of appropriate network services for designated regions.

The Moreton Bay region of Queensland is the third largest local government area in

Australia and is also one of the fastest growing areas in Australia. Population growth is expected to continue over the next 15 years which will cause a significant transportation problem if the use of private cars grows at the same pace.

Known as the Moreton Bay Rail (MBR), work began in 2013 on an integrated public transport corridor for the region with vehicle, cycle and pedestrian access. The corridor includes a 12.6km double-track rail line to provide a safe and reliable transport network.

Currently over 80% of Moreton Bay residents travel to work in a private vehicle.

It is expected that nearly 6,000 people will use the Moreton Bay train daily. Because MBR will significantly improve public transport in the area, it will provide an incentive for people to make the switch to public transport. Current driving time is one hour from Kippa-Ring to the CBD in Brisbane.

While rail service will be upgraded, an additional effect is to reduce congestion on the road network for journeys that can't be made using public transport. In addition the rail corridor provides a proven method to reduce carbon emissions; every full train equates to removing 600 cars from the road network.

The MBR project is funded in part by the Nation Building Program of the Australian Government. The Queensland Government and Moreton Bay Regional

Council are co-funding the \$1.47billion project to bring to fruition a visionary project that began through land acquisition in the 1980s.

Finalisation of alignment and station sites concluded with the design development and creation of the TrackStar Alliance in 2013 to deliver the project. TrackStar Alliance is an integrated infrastructure delivery business that harnesses the skills of four business partners with Queensland Transport and Main Roads; Hassell, Thiess, Aurecon and AECOM. Each of the private sector partners provides specific skills for this complex project:

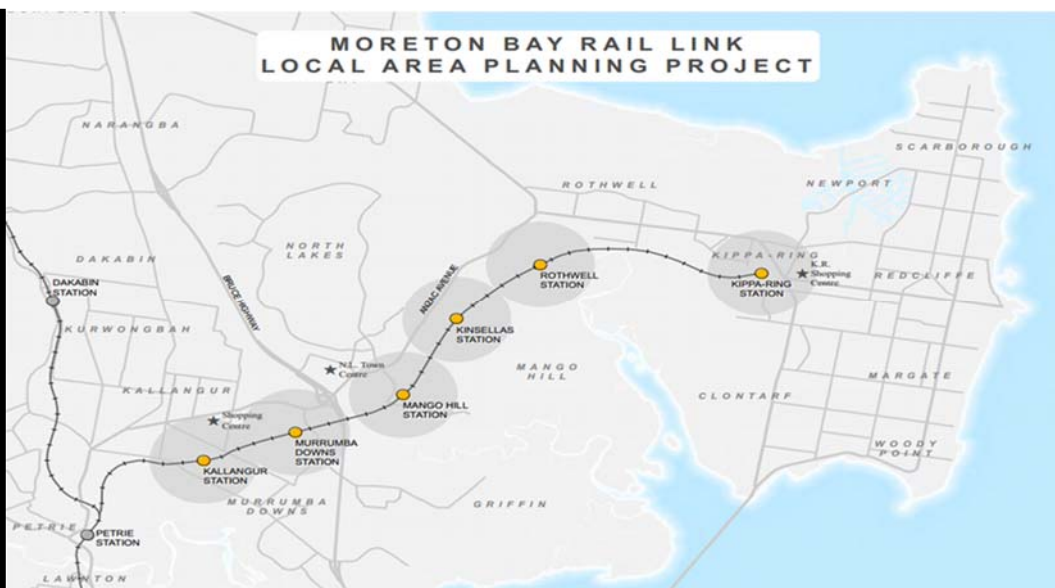
- **Contractor: Thiess**
- **Architects & Urban Designers: Hassell**
- **Technical Services: Aurecon**
- **Engineers: AECOM**

7.2.2 Project Overview

Location

The Moreton Bay Rail (MBR) project involves construction of a new 12.6km dual heavy track passenger rail line between Lawnton and Kippa-Ring that includes six new railway stations.

The integrated transport passenger rail corridor is located approximately 23 kilometres north of the Brisbane CBD within the local government area of Moreton Bay Regional Council. The corridor extends eastward from Petrie railway station (27.5 km by rail from Central Station, Brisbane) to Anzac Avenue in Kippa-Ring.



<https://www.moretonbay.qld.gov.au/uploadedFiles/common/projects/moreton-bay-rail-link/MBRL-Map.pdf>

Key Features

- **Rail corridor**

The completed Moreton Bay Rail link will be 12.6km of dual heavy track and structures.
- **Stations**

The six new stations: Kallangur, Murrumba Downs, Mango Hill, Mango Hill East (previously called Kinsellas Road), Rothwell and Kippa-Ring. All stations will provide full passenger services: 175m long side platforms, walkways, ticket offices, waiting facilities, park and ride facilities and bus/train interchanges.
- **Road and rail bridges**

MBR construction includes 22 major bridge structures. In some locations, such as the Bruce Highway and Brays Road in Murrumba Downs, a rail bridge will be built over the existing road. At Kinsellas Road East a new road bridge has been built over the rail line.
- **Cycling and walking (paths and facilities)**

MBR will provide an opportunity to upgrade user-shared pedestrian and cycling links within the Moreton Bay region specifically related to new rail station access.



Moving 371,000 cubic metres of materials from the Petrie station site. These materials were re-used at other locations along the rail corridor to build up the rail embankment.

Cost

The \$1.47billion required for the project is provided jointly by the Australian Government (\$742million), Queensland Government (\$300million) and Moreton Bay Regional Council (\$105million). The Queensland Government, through Queensland Transport and Main Roads, is delivering the project on behalf of the three funding partners. The Queensland Government has also contributed land valued at \$120million to the project.

Duration

- **2011:** Develop detailed design, procurement for construction and acquisition of remaining properties
- **2012–2016:** Preconstruction activities and construction
- **2016:** Finalise construction and commence rail services (weather permitting)

7.2.3 Design, Management and BIM

During the last 20 years different IT companies have invested in software to obtain integrated environments for effective collaboration between architects, engineers and contractors. Development of these tools is based on the premise that collaboration between all project participants through ITC will enhance construction process and increase work efficiency. This focus has encouraged model-based (3D) design solutions including object-oriented BIM environments.

Designers for all phases of construction projects use a range of software with specific functions. These occupation specific software preferences, as well as the organisational cycle of ITC upgrades, are major drivers for the global effort to provide a unified means of information exchange within each construction project. Currently, integrating 2D with approaches to 3D models is driving software development and project collaboration.

Table 3: Examples of the differences between the software used by the civil engineers at QTMR (string based) and the architects at Hassell (object based).

Type of Process	Type of Object	Responsibility	Tool	Potential			Use			Integration					
				2D	3D	BIM	2D	3D	BIM	FM	Clash Detection	Interoperability			
Road/Rail Geometric Modelling Planning & Design Systems (String Based Design)	Roundabout	Civil Engineer	ARNDTA: QTMR Numerical Design Tool	✓			✓						2D drawings		
	Roadside objects including: walls, embankments, and service poles.	Civil Engineer	Main Roads 12d Customisation	✓	✓	✓	✓	✓	✓	✓	✓	✓	Export via IFC to Navisworks Also forms QTMR BIM		
				✓	✓	✓	✓	✓	✓	✓	✓	✓	2D drawings		
				✓	✓	✓	✓	✓	✓	✓	✓	✓	2D drawings		
Computer Aided Drafting (Object based Design)	Rail stations	Architect	SketchUp	✓	✓			✓					Visualisation 2-way with Revit, multiple iterations		
				✓	✓									2D drawings Accepts IFC for clash detection (worked better than Navisworks) Import into Navisworks	
				✓	✓									Import from Revit & IFC No export	
				✓	✓										Concepts
				✓	✓										



Hassell 3D model of the Rothwell Station and Landscape for concept communication

As the client and eventual owner of the MBR all documents for the project should ultimately be available to Queensland Transport and Main Roads. Their customised BIM system is the 12d product. A significant number of construction design and implementation software tools have been researched and developed specifically for QTMR. Because projects have standard requirements such as road signage or lighting, all contractors are required to use the QTMR software for some parts of a project to ensure that documentation is compatible with their customised 12d system.

Hassell use SketchUp and Rhino/3D Max for early phases of design. Aurecon have been using Navisworks for supporting BIM-enabled design since 2000. AECOM uses AutoCAD 3D and all these partners

have BIM modelling expertise with Revit.

The MBR project design has two distinctive components as indicated in the accompanying table on the previous page. The first relates to the buildings and architectural elements that use object based BIM solutions as described above. However, these object based models do not fit easily into the 12d string based modelling platform preferred by QTMR.

The second project component relates to geometric elements including railway embankment alignments, the access roads, bridges, landscaping and the pedestrian walkways. In this domain, string-based modelling solutions, such as 12d are considered essential because working with object based BIM solutions is painstakingly inefficient. For instance, Alignment strings in 12d provide independent horizontal and vertical geometry and are created and edited interactively on plan and section views.

Integration of models generated from the two different approaches does take place within Navisworks via IFC export or direct export. This process has proven to be challenging (in terms of time and skills availability), but the MBR project team are effectively using IFC object data in the Navisworks software for project interoperability. However, a major shortcoming remains the lack of two-way processing once the models are in Navisworks.

Station design is an essential ingredient in making public transport attractive to users and the community – and getting the design for each station right is a key priority for the Moreton Bay Rail project team.

Benefits of BIM

- Easy to communicate a concept using a 3D object based model
- Identification of incompatible fixed 3D objects (clash detection) in a working model is more effective for project progress
- Integration of required design elements modelled in QTMR 2D software

The variety of processes and products that are required in the construction of the MBR means that problems will arise and solutions need to be found. Building information modelling (BIM) is a solution beneficial during the design stages.

Revit and AutoCad, as authoring tools, create 3D models that are great problem solvers for clash detection. This type of modelling means being able to see three dimensional walls, floors, windows and columns which aids detailing and especially design changes. Because building objects have been the focus of much of the BIM development during the last 15 years, architectural skills in BIM are the most advanced.

The object based model design process flow for MBR is:

- Conceptual model in SketchUp
- Design development in Revit
- Developing model returns to SketchUp for visualisation
- A continuing iterative process to integrate changes into an acceptable developed model
- Developed 3D model analysed (e.g.

clash detection) within Navisworks

Providing project consultants (project managers, estimators, engineers, contractors) with a 3D model is a valuable communication tool. The value of clash detection analysis at an early stage assists with the evolution of co-ordinated project documentation.

An important feature of the MBR transport corridor is the six new stations. Each station is strategically located to connect the rail corridor to their wider community with the aim of providing evidence of the benefits of public transport. Each of the six stations will have a unique design to set it within an urban growth precinct. BIM is used by Hassell to design the stations and integrate them into the road, rail, cycle and pedestrian systems. At the same time efficiencies were obtained by standardising elements of each of the stations such as platform design, exterior station overhangs, and ramps to parking areas.

A major shortcoming of Navisworks 3D modelling is the lack of two-way processing once the models are in Navisworks. This makes working with object based BIM solutions risky (due to possible loss of data) for the project components that use models generated with string based software. The object based models also do not fit easily into the 12d string based modelling platform preferred by QTMR.

As the client QTMR has the need to provide safe public transport systems based on research led standards that are embedded in their operating and management systems. Private

providers, focused on competitive advantage, aim to be ahead of the pack with the latest IT solutions. These differences of purpose and organisational construction management systems are converging with increasing use of increasingly effective 3D modelled construction solutions.



Information for this case study was obtained from:

<http://www.tmr.qld.gov.au/Projects/Featured-projects/Moreton-Bay-Rail.aspx#projectplan>.

7.3

Case Study

3

Memorial Park Underpass, New Zealand

7.3.1 Project Summary

The National War Memorial in Wellington, New Zealand commemorates the more than 300,000 New Zealanders who have served their country and the 30,000 who died in this effort. The Carillon tower was the first section of the National War Memorial that opened in 1932. It commanded a dominant position overlooking the city and was easily visible from most areas of the capital. However urban growth has diminished its iconic position.

To regain pride of place, a Memorial Precinct to mark the centenary of the First World War is currently under construction. It includes the Carillon, the Hall of Memories, the Tomb of the Unknown Warrior and a new Park and Ceremonial Plaza. Precinct construction requires putting a section of State Highway One (Buckle Street between Tasman, Tory and Taranaki Streets) underground with the Memorial Precinct on the top.

The development is collaborative between New Zealand Transport Agency (NZTA) and the Ministry for Culture and Heritage (MCH). Announcement of the

project coincided with passage of legislation allowing NZTA to accelerate construction of the Underpass to allow the necessary time for the Ministry for Culture and Heritage to complete the Park for services on 25 April 2015, Anzac Day.

The Memorial Park Underpass Project scope is outlined in four well defined phases:

- Phase one - site preparation for the tunnel
- Phase two - dig the trench
- Phase three - construct the tunnel
- Phase four - build the park on top of the tunnel

It was estimated that development of the Park would cost NZ\$12 million. Wellington City Council agreed to contribute \$2.11 million towards that the cost. The balance of the funds for the Park development is the responsibility of the Ministry of Culture and Heritage. The NZTA initially earmarked \$80 million for the transport works.

The Australian and New Zealand Army Corps (ANZAC) formed in 1916 (troops from the *First Australian Imperial Force* and *1st New Zealand Expeditionary Force*) fought in Gallipoli. This major battle is commemorated in both countries on 25 April, ANZAC DAY. The countries continue to share memorials and services. The Australian contribution of AU\$5 million is for a dedicated Australian Memorial to be placed on the Ceremonial Plaza.

Design and Construction for the project is by The Memorial Park Alliance that includes both government agencies, NZTA and MCH and four private providers: Downer, HEB Construction,

Tonkin & Taylor and URS. The Memorial Park Alliance deliverables are the three lane underpass for NZTA and the Memorial Park on top of the underpass for MCH.

However three major constraints place pressure on project delivery:

- An 18 month deadline, ANZAC day 25 April 2015 for WWI commemoration ceremonies
- Works are in the CBD of Wellington, New Zealand, a major earthquake zone
- Significant heritage in the construction site, over and above the War Memorials

7.3.2 Project Overview

The National War Memorial Park and Underpass Project will result in an iconic international War Memorial in the city of Wellington, the capital of New Zealand.



Urban Design conceptual model of Memorial Park

Location

The underpass is a reinforced concrete structure approximately 180m long. The structure will allow the 3 lanes of State Highway 1 to be placed underground from Sussex St to Taranaki St, a main traffic route in the CBD of Wellington. Construction of the tunnel creates the needed ground level space to develop the National War Memorial Park especially an enlarged Ceremonial Plaza that will be built above the underpass. At the same time the underpass is considered part of the Memorial Precinct.

Key Features

- **Surrounding roadworks**

Diversion of Buckle Street, re-design for entry and exit to tunnel, necessary temporary traffic, cycle and pedestrian travel arrangements.

- **Underground services**

Up-grading and relocating underground city services including storm water for water table stability.

- **Trench**

Demolition of current roadways. Massive earth works: digging a 180m trench and hauling soil to other city locations. Construction and placement of temporary and permanent stabilisation walls and piles.

- **Tunnel (underpass)**

Construction of the tunnel involves two components: basic road design and build

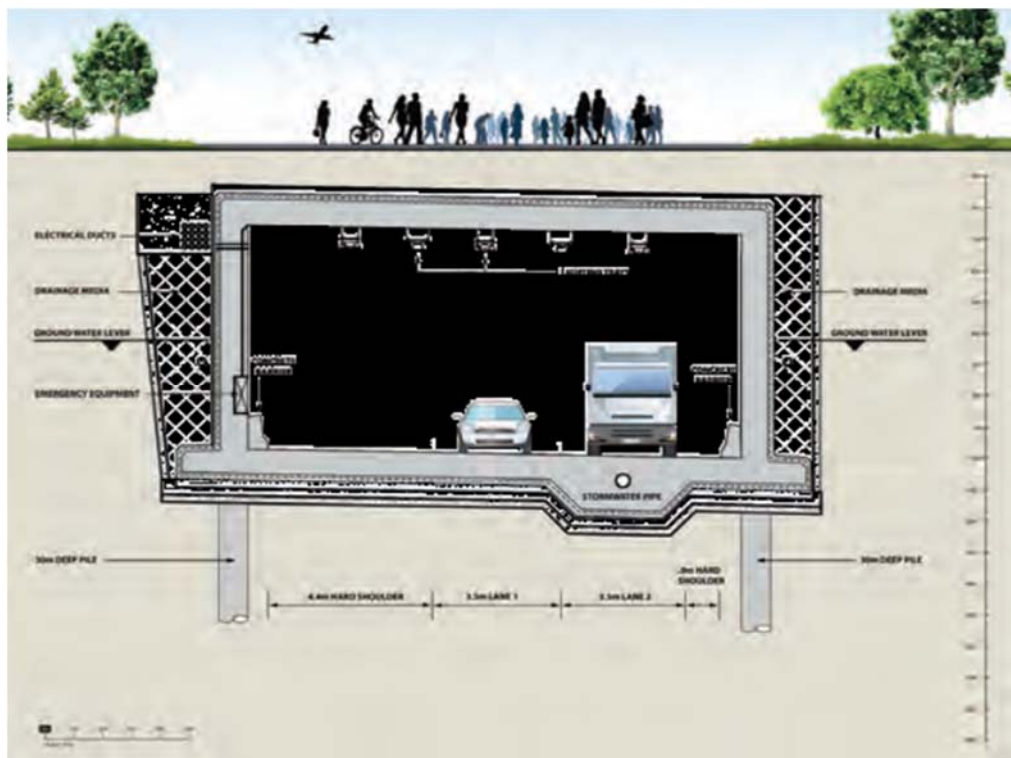
for construction of a basic box (slab, walls, roof) using traditional construction methods; earthquake proofing.

- **Park**

Re-design and re-surface park area; terracing; planting trees & shrubs; adding rock features & sculptures including Australian stick men (on the roof of the underpass); resting place for Crèche.

- **Heritage**

Buckle street archaeology, dealing with buried treasure; moving, renovation, earthquake proofing Home of Compassion Crèche built in 1914. Preservation of 100 year old brick Wellington City sewer and Mount Cook Police Station and Barracks built in 1893.



Engineering section of tunnel and piles

Cost

The New Zealand Transport Agency (NZTA) originally earmarked \$80m for the undergrounding of Buckle Street. However, the tight time frame for completion and the inner-city location constraints has meant that costs have increased as deadlines were met, while dealing with unforeseen problems.

For example, in the Autumn of 2013 the steel sheet piles that were to be used for the trench retaining wall near the Mount Cook Police Barracks (built in 1893), hit a

layer of weathered greywacke rock. After testing a number of options, the choice was to hammer rather than vibrate the piles into the ground a costly option requiring two very large cranes. The September 2014 estimate is in excess of \$120m.

Duration

The New Zealand Parliament passed the National War Memorial Park (Pukeahu) Empowering Act 2012 to assist NZTA make the vision of a National War Memorial Precinct a reality inside a tight timeframe of 18 months.

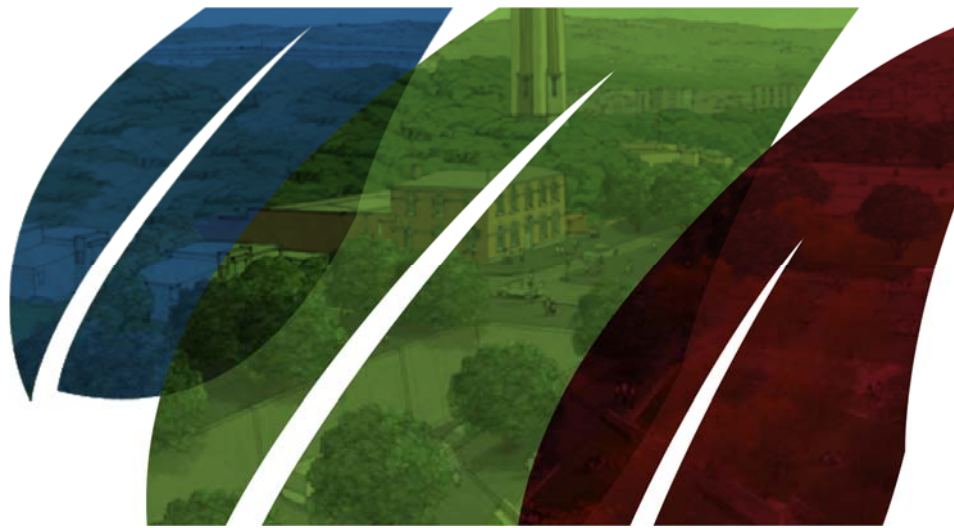
● Phase 1. Site Preparation: August 2012 – January 2013

Designing and planning for construction of the tunnel and the road diversion.

The first operation on site was to divert a section of State Highway 1 (Buckle Street) to a temporary position enabling work on the underpass to begin. The major part of the diversion was to remove, update or stabilise the necessary city services that were located underground where the trench was to be dug. Examples of services: underground

stormwater, water main, sewage, gas, electricity and telecommunications pipes.

In addition, 6.5km of new pipes were required (including new valves and steel pipe connected to the 100-year-old water main under Tory Street) to maintain water table stability.



● Phase 2. Dig the Trench: February 2013 – September 2013

Construction of the trench was in fact site preparation for the underpass.

Mass-haul:

To make a hole 300 metres long, 18 metres wide and at its deepest point 12 metres deep required moving dirt 32,281 cubic metres of soil (for use in suburban development). This amount of mass-haul equated to 3,586 truck and trailer loads, all moving through busy CBD streets. The dimensions of the hole created sufficient space for both temporary and permanent retaining walls.

Temporary trench retaining walls:

The walls were necessary to create the construction site for the tunnel. Temporary kingposts and timber walls protected the ground and the workers in the trench. The wall was made up of 285 kingposts reaching 15 metres into the ground plus 14,381 timber posts slotted between the kingposts.

Permanent retaining walls:

A 90m long permanent steel sheet pile retaining wall was needed in front of the Mount Cook Police Barracks and Tasman Gardens Apartments. These interlocking steel sheet piles (225) were embedded 15 metres into the ground. This protects the foundations of these heritage buildings that are close to the tunnel. The importance of the wall is to prevent loss of the water table because of the addition of a large structure at the bottom of the hill.

Ground anchors:

Earth quake zones require specialised building methods. To ensure stability of the permanent retaining wall required 558 anchors (each 13 metres long) to be installed sideways into the ground. They are tied into both the kingpost walls and sheet pile walls for added strength.



Australian Memorial

The Australian Memorial was designed by Australian architectural firm Tonkin Zulaikha Greer. It features 15 columns made from rugged red sandstone as symbolic of the 'Red Centre' of Australia. The columns will be surrounded by Australian eucalyptus trees, a typical Australian landscape.

Re-design and re-surfacing of the memorial area includes: terracing and planting trees & shrubs; addition of rock features & sculptures including the Australian stick men; locating the Home of Compassion Crèche (a child care

centre) in its final resting place. The Crèche was built in 1914 for Mother Suzanne Aubert and has been recently placed on the New Zealand Historic Places Trust Register as the first purpose built crèche in the country.

View of underground services during Park construction (October 2014)



7.3.3 BIM Capability and Capacity

The Project Management team has the responsibility of ensuring completion of the scope of the project as defined by the clients - New Zealand Transit Agency, the New Zealand Ministry of Culture and Heritage, Wellington City Council, and the Australian Office of War Memorials.

During the last 20 years, different IT companies have invested in software development to enable effective collaboration between architects, engineers and contractors through an integrated modelling process.

Development of these tools is based on the premise that collaboration between all project participants through ICT will enhance the construction process and increase work efficiency.

Platform and software developers have played a vital role in creating the evolving

BIM environment based on the concept of 3D interoperable modelling. Integrating 3D modelling capability and capacity is the necessary foundation for completing the complex construction projects of the 21st century.

In order to meet their obligations, a team of designers for specific phases and specific processes used a range of software for dedicated project components. To complete the scope of the project, within the site and time constraints, the Memorial Park Alliance project team utilised 3D modelling for the design and management of some project components.

This report focuses on the BIM application to this brown field project, specifically the application for underground services.

Underground Services (water, telecommunications, gas and electricity)

Benefits of BIM

- To fit together a complex integration of infrastructure and services within extremely tight location constraints
- To solve the complexity of the geographic and physical constraints of existing and new services
- To provide visualisation of the design resolution

The geography of the city of Wellington means that all services including electricity are placed underground in the CBD. Because the CBD is on the harbour, many services (especially storm water) funnel through the construction site. These factors place a major constraint on the project services work: services cannot be interrupted because they link to a variety of suburbs, necessitating continuous business and residential use. Thus, the complexity of the task for the Underground Services team: to relocate, preserve, up-grade or install new services.

Tonkin & Taylor contributed their BIM expertise in Underground Services design and management to the Alliance. Their capability includes the possession of knowledge and skills to integrate differing types of 3D modelling software.

The first step for the Underground Services team was to ensure a complete model of current services as the AS-IS 3D model for all phases of the project. To do this they dug test pits to locate the multiple services. The data from these sites became the foundation for their AS-IS model. The AS-IS model provides important decision-making information such as ensuring locating gravity system

over non-gravity systems.

Throughout the project the Underground Services model is expected to be constantly changing. Changes result from a rigorous quality control of both the model and the site. The model was designed with AutoCAD Civil3D. This software supports continuous design changes, generating documentation and working collaboratively. Civil3D models are able to integrate infrastructure data from 12d and MX and provide detailed information for construction workers onsite. The most important feature of the 3D visualisation is for design resolution of the multiple layers of services and visualisation of the limitations of space.

Relocating old underground services before digging the trench





An example of a critical design resolution was to fit the tunnel between the fragile 100 year old horse shoe shaped brick and mortar sewer and the other services which were located over this structure. Services for stormwater and telecommunications had to remain under the tunnel roof.

100-year-old sewer under Tory Street, Wellington, New Zealand

The effectiveness of the continually changing 3D model was because the Taylor & Tokin Underground Services team had both experience using BIM enabled software, as well a sufficient number of successful experiences in solving construction problems using the 3D design resolution (commonly called clash detection) functionality. Indeed an important aspect of their success is based on understanding the common limitations of both 2D and 3D software modelling and design detail processes.



New valve to connect with the 100 year old sewer

Challenges of Enabling BIM

● Public road and rail infrastructure project software interoperability

The Memorial Park Underpass project has been designed and managed by 60 designers, construction managers and support staff. The construction site constraints were embedded in a number of local community requirements: continued use of the local primary school; minimising disruption of Wellington airport traffic; minimising inconvenience for residents close to the construction site; as well as continual adaptation of local CBD traffic routes. All of these constraints required a significant amount of flexibility to deal with unknown problems. The capacity to solve

these problems, especially within the 18 month project completion deadline was dependent on ITC for design resolution.

BIM technologies have been presented as a solution to all problems within the construction industry. However, challenges remain. BIM has many definitions (depending on occupation and software claims) making transfer of 3D models on complex construction projects risky. While buildings are modelled in object based software, transport infrastructure design construction models use string based software.

Currently 12d is the standard modelling system used by Australian and New Zealand publicly funded transport authorities. Many transport infrastructure projects involve alignments to the curvature of earth's surface (especially over long distances). Therefore it makes sense to use 3D modelling software that provides visualisation of geographic contours.

The Underground Services team was able to create and use object-based

visualisation for modelling the replacement, removal and relocation of the underground services (water, gas, telecommunications, electrical) on this complex inner-city iconic heritage project. However, integrating their model into the string based models of other components of the infrastructure project was always 'too difficult'.



Anzac Day, 25 April 1932: 50,000 people stand in silence for the dedication of the Carillon on Mount Cook - the first of the National War Memorial buildings. Source: Alexander Turnbull Library; Ref: 1/1-020293-G; Photo: Sydney Charles Smith 1888-1972.

Information for this case study was obtained from:

<http://www.nzta.govt.nz/projects/memorial-park/index.html?r=1> Additional information was provided by members of the Memorial Park Alliance.

7.4 Case Study **4** The Design of Perth's Light Rail Network, Western Australia

7.4.1 Project Summary

Metro Area Express, or MAX, is Perth's proposed 22 km light rail network that will run from Mirrabooka in the north to the CBD, before splitting into two branches to Victoria Park Transfer Station in the east (via the Causeway) and to QEII Medical Centre in the west (via West Perth). This visionary project will introduce a new era of public transport in Perth, supporting the city's transformation by providing a frequent, high-capacity service in the inner-north and central west and eastern suburbs of Perth.

Essentially a modern tram system using electric rail cars, the new light rail system is quiet and efficient and will be built on existing streets but largely separated from general traffic. The project is a catalyst for city change, being coordinated with land-use planning with

the intention of stimulating revitalisation and new developments along the proposed alignment.

Due to critical State budget pressures, the State Government has deferred the MAX Light Rail project for three years, which will see overall completion of the project by late 2022.

The MAX Light Rail project is a transformational project, and the State Government is committed to delivering the project in full. The revised timeframe will see a call for tenders in early-2018, construction commencing in 2019, with first services running by late 2022.

BIM has been used in several ways on the MAX Light Rail project but mainly in the design stage of the project at the moment.

7.4.2 Major Stakeholders

The Integrated Services Team (IST) established for the project included AECOM, as part of the Joint Venture and the Western Australia Department of Transport.

7.4.3 Project Description

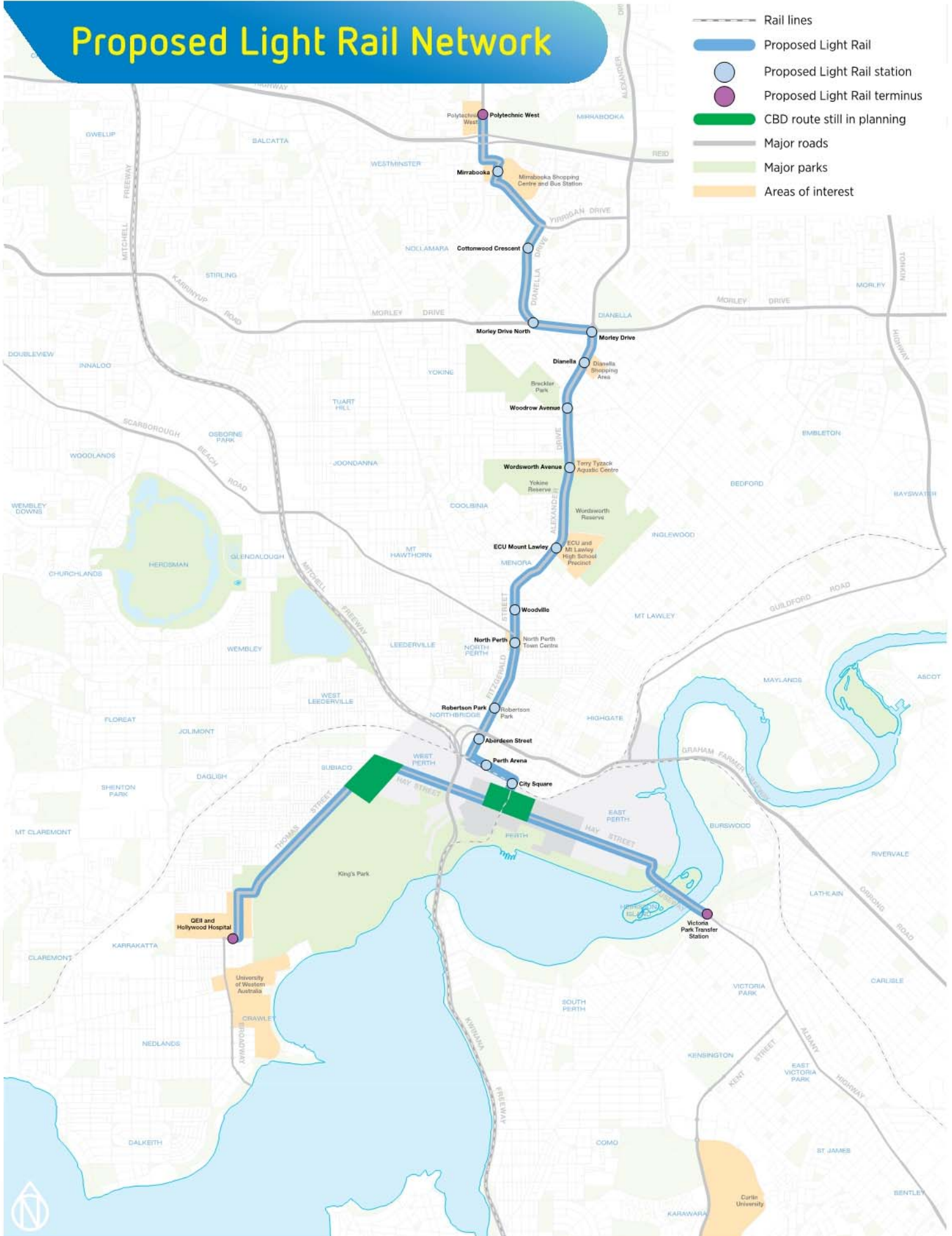
The IST functioned in a collaborative and innovative way to successfully deliver the Business Case including the following project disciplines; preliminary design (including systems), traffic network operations modelling, environmental approvals and sustainability, land use planning and stakeholder and community management.

7.4.4 Project Delivery Method

The proposed project delivery method is Design – Bid – Build. The State Government has placed the project on hold.

Proposed Light Rail Network

- Rail lines
- Proposed Light Rail
- Proposed Light Rail station
- Proposed Light Rail terminus
- CBD route still in planning
- Major roads
- Major parks
- Areas of interest



7.4.5 BIM Tools and Uses

- **Infrastructure Software 12d model**
Provided the platform for the production of the existing feature survey and the proposed road design model, including platforms and retaining walls and the drainage assessment.
- **Autodesk AutoCAD Civil 3D**
Provided the platform for the production of the existing in ground and above ground service model.
- **Bentley Rail Track**
Provided the platform for the production of the proposed rail design model.
- **GIS Software Esri**
Provided the platform for the production of mapping all of existing heritage, existing environmental, building, existing services, and proposed design.
- **Clashes Detection / MTO / 4d Sequencing using Autodesk Navisworks**
Provided the platform for the coordination of all models, review tools, clashes and cost reporting tool.
- **Traffic Software: LinSig**
Provided the platform for the Intersection traffic analysis.
- **Traffic Software: SIDRA 6**
Provided the platform for the isolated intersections analysis.
- **Traffic Software: STEM**
Provided the platform for the overall traffic Analysis and future traffic volume modelling.
- **Traffic Software: Commuter micro-simulation**
Provided the platform for the overall traffic volume Analysis and future traffic volume modelling.

7.4.6 BIM Technical Analysis (Pros)

BIM uses were adopted only at the design stage of the project, such as:

- Land Use and Transportation Planning
- Public Information and Communication
- Constructability Reviews
- Traffic Impact Simulations
- 3D Coordination
- Engineering Analysis
- Rule-based Model Validation
- Clash Detection
- Quantity Take-off
- GIS tracking



7.4.7 BIM Model Development and Process

The details of the model could not clearly be defined by the LOD-Specification as the nature of the project is Civil infrastructure. Nevertheless, the LOD Specification section G. “Building Site works” could be used as a base for clarifying the details of the model. It could be projected that most elements modelled were at the average level of LOD 200. For elements that fell out of this parameter would be categorised under section G “fundamental LOD definitions were applied”.

The DoT or PTA is the owner of the model, the Intellectual property and the method of information management in creating the model. Yet, the political

sensitiveness of the project was observed in the project, which all employees were required to be bound to a cabinet confidential agreement. There were some structured policies that only allowed approved users to access the information on the server and project folders. The GIS web viewer had a user login with additional security to limit only defined IP address access, allowing only access within predefined locations. The model was also audited regularly through an internal process to comply with the defined quality systems.

7.4.8 BIM Collaboration and Workflow

The proposed 22km light rail network had a magnitude of existing information. Fig. 16 shows the overall BIM workflow. The existing information could be categorised into two main data sets, namely, (a) physical data on the existing conditions, and (b) spatial data on the flows of existing vehicle and human traffic conditions. The physical existing information were derived from existing records and survey. The 22km network was surveyed using a traditional method of feature survey and a laser scan method. Both survey methods provided the information for the existing

conditions required in the model development. It would identify areas or elements as posing risks to the project and to be communicated clearly for future risk mitigation. The existing survey information data set was provided and synchronised in Infrastructure Software 12d model. The survey information was exchanged with other software platforms via Landxml. Landxml provided the common platform to exchange simple (non volumetric) information between platforms.

LRT BIM WORKFLOW

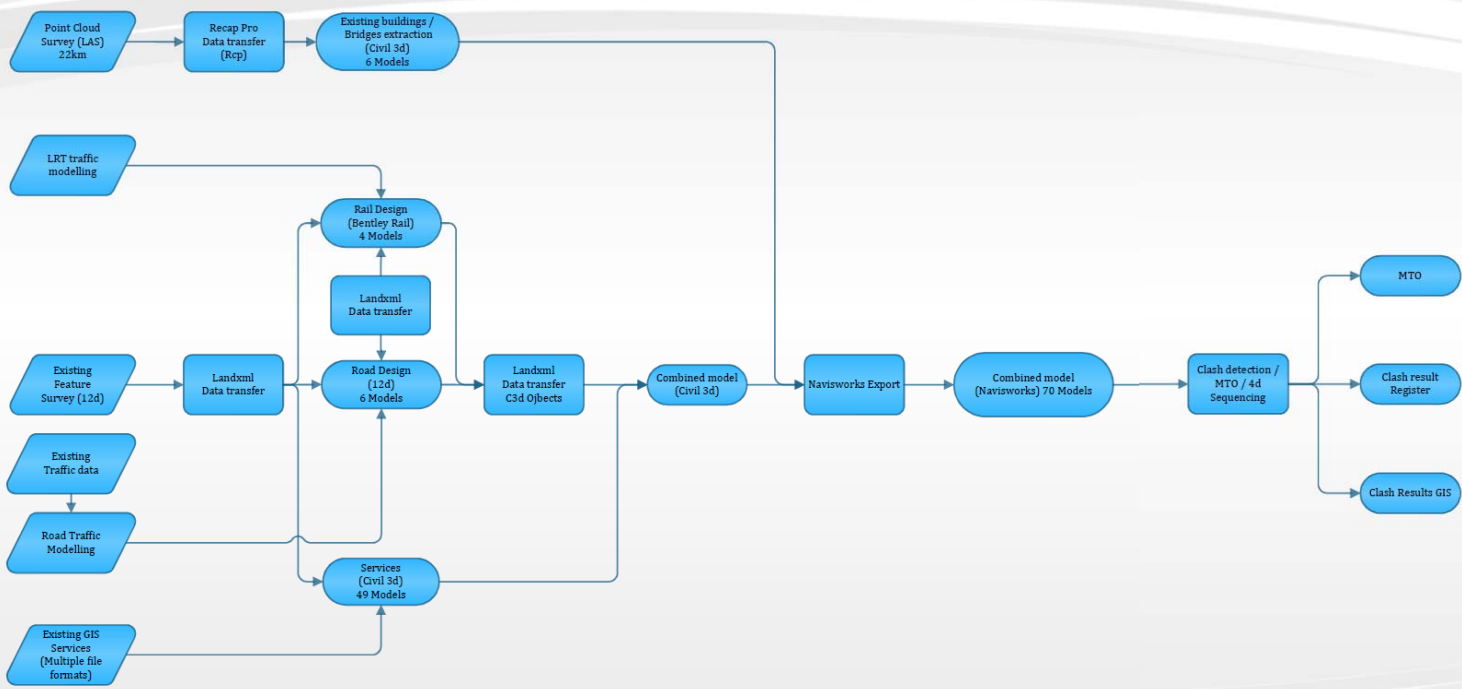


Fig. 16 LRT BIM Workflow

The point cloud information data set was provided in Leica LAS format. The point cloud data was processed using Autodesk Recap to refine and index the point information into the federated model and broken into key areas which required surface /volumetric model information

The existing utilities information data set was obtained from multiple asset and government agencies. It included the GIS asset records and spatial mapping systems. 'A.S.5488: Classification of subsurface utility information SUI' was applied to the existing utility information to provide a uniform data structure. The processed information with the schema from AS5488 was stored in the Ersi Shape

GIS data base. Bentley Subsurface utilities engineering software was adopted for creating and maintaining the data form SUE. The data would be in the shape file format and to be displayed in the project GIS view. Landxml was also used to categorise and provide the physical/spatial/ visual data.



7.4.9 Conclusion

BIM has been used in several ways on the proposed MAX Light Rail project, including building intelligent databases of key project components and systems; overlaying of existing services, rail, road, electrical system, 22km of point cloud laser scanning and civil/structural elements to identify and eliminate conflicts (clash detection); and production of civil/structural backgrounds. Virtual clash detection eliminates

field construction changes that are identified as costly and provide challenges to the project schedule and overall budget. Two dimensional drawings were extracted from the BIM model, which was developed with all of these factors in mind, for use in the business case.



7.5 Case Study **5** Auckland City Rail Link, New Zealand

7.5.1 Project Summary

The City Rail Link (CRL) will extend Auckland’s passenger rail system past Britomart to connect to the existing regional rail network at Mt Eden. Britomart will become a through station with new stations near Aotea Square and Karangahape Road, and a redeveloped station at Mount Eden. The current

phase is to undertake preliminary design for use in procurement and detailed design of an Enabling Works package. The CRL will use twin 3.4km long tunnels up to 33 metres below the city centre streets. It is estimated it will take five and a half years to build at a cost of NZ\$2.5 billion when inflated to 2024 prices.

7.5.2 Major Stakeholders

Table 4 shows the major stakeholders in the project.

Table 4: Major stakeholders

Stakeholder Name	Role
Auckland City Council	Funder
Auckland Transport	Client
Aurecon	Principal Technical Advisor – Principal Consultant
Aurecon	Rail Systems, Structure, Civil, Tunnelling, Utilities, Alignment, Survey
Jasmax/Grimshaw	Architecture
Mott McDonald	Building Structures and Services



7.5.3 Project Description

Two new underground stations at Aotea (11m depth) and Karangahape Road (33m), will be developed and Mount Eden Station will be redeveloped as illustrated in Fig. 17. It will involve cut and cover construction along Albert Street and at Eden Terrace. The majority

of the construction will be using a tunnel boring machine (TBM), which is 7.5 metres in diameter. It will excavate about 1 million cubic meters of spoil. Eighty-eight subterranean properties will be affected and benefited by the tunnels.



Fig. 17 Design of the Project

7.5.4 Project Delivery Method

The project was a Reference Design Project, where Aurecon was engaged as the Principal Technical Advisor. Future engagements are expected to be Design-Build with Contractor based design teams.

7.5.5 BIM Tools and Uses

At the design stage, six software packages were used. Table 5 shows the details for the software.

Table 5: BIM tools

BIM Package	Version	Build/Service Pack	File Format
Revit	2014	20131024_2115(x64)/ Update Release 2	.RVT
Civil 3D			3D.DWG
AutoCAD			.DWG
Bentley MX	SS2	08.11.07.537	.DGN
12d	VERSION 10	K	.12DA
Navisworks Simulate	2014	11.4.0.101763	.NWD, NWC, NWF

7.5.6 BIM Technical Analysis (Pros)

BIM uses were adopted only at the design stage of the project, such as:

- Public Information and Communication
- Constructability Reviews
- Traffic Impact Simulations
- 3D Coordination
- Engineering Analysis
- Clash Detection
- Quantity Take-off

7.5.7 BIM Technical Analysis (Cons)

- Public Information and Communication
- Constructability Reviews
- Traffic Impact Simulations
- 3D Coordination
- Engineering Analysis
- Clash Detection
- Quantity Take-off

7.5.8 BIM Model Development and Process

The aim is to see BIM used as the primary drawing production environment and not as a retrospective tool, so that the functionality of BIM can be used to assist the design coordination and optimisation. This will involve the establishment and execution of collaborative processes using 3D modelling tools, and the exchange and coordination of digital models to achieve the following objectives:

- Significantly reduce clashes between the design intent of different systems (for example, hydraulic services and structural elements) to establish geometric presence and to pass the following benefits to the design and construction team:
 - Foster confidence in the design intent
 - Shorten construction time compared with traditional construction processes
 - Minimise re-work and variations during and construction phases

- Enhance project quality and workers' safety on site

All drawings which are relevant to defining the project in terms of its physical envelope and spatial coordination will be produced in a 3D CAD format with Building Information Modelling (BIM) capability. This includes station and tunnel layouts, station and tunnel building services, major equipment layouts, major station and tunnel components, etc. Drawings which are not relevant to this spatial aspect need not be developed to this standard but where relevant shall be capable of being cross referenced or input as schedules to the overall BIM model. These excluded drawings may comprise system architecture and schematics, reinforcement drawings, schedules, explanatory notes, etc.

Overall, IP and ownership remain with the consultants put with an implied license used by the client. The LOD for the Reference Design Phase will be minimum LOD200.



7.5.9 BIM Roles and Responsibilities

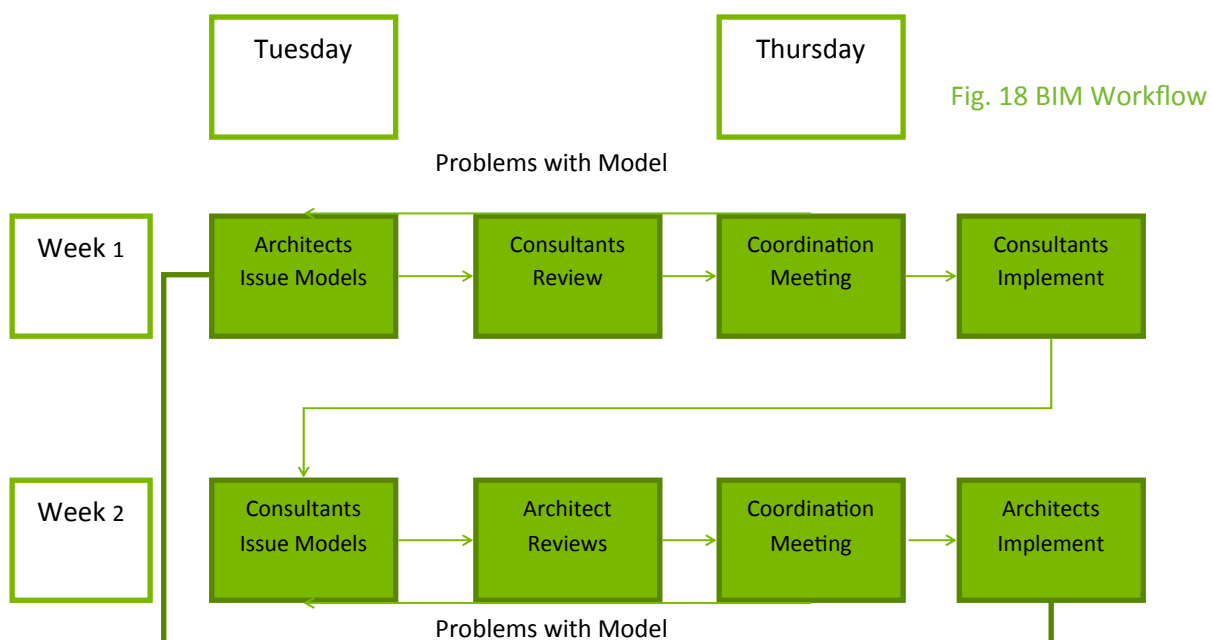
Table 6 shows the BIM roles and responsibilities in the project.

Table 6: Roles and Responsibilities

Defined Role	Responsibility in Business Management Process development	BIM Responsibility
BIM Manager	Coordinate BIM use on project, determine schedule of use, sharing activities, quality control, modelling responsibilities and documentation in business management	Oversight, Management, Execution and Model Exchange
Lead BIM Coordinator	Assist BIM Manager	Implementing BIM Manager instructions with Reference Design Team. Representing BIM Manager.
Architectural Team	Design Execution – formulate with BIM Manager. Map BIM use for architectural design.	Modelling and Review, Model Exchange.
Structural Team	Engineering – formulate with BIM Manager. Map BIM use for structural simulation and documentation.	Modelling and Review, Model Exchange.
MEP Team	Engineering – Formulate with BIM Manager. Map BIM use for simulation and documentation	Modelling and Review, Model Exchange.
Alignment Team	Support. Provide data in the specified exchange format	Data development and integration
Civil Team	Support. Provide data in the specified exchange format	Data development and integration
Utilities Team	Support. Provide data in the specified exchange format	Data development and integration

7.5.10 BIM Collaboration and Workflow

Coordination meetings were held weekly with model managers coordinating their respective areas and maintaining an issues or coordination register that was tracked weekly with percentage completes, until they were closed out completely. Fig. 18 illustrates the workflow of the design stage.





7.5.11 Conclusion

This is a large project, which will last for five and a half years and be built at a cost of \$2.5 billion. The consultants were engaged with very little definition of what was required of BIM for the project. The project has developed an interest into BIM uses in Public Information and Communication, and Constructability Reviews, which two methods could be improved further in the design stage.

Appendix A – Existing BIM Guidelines

Country	Organisation	BIM guidelines & standards	Year	Description/Objective
Australia	Australian and New Zealand Revit Standards	Australian and New Zealand Revit Standards	2012	<ul style="list-style-type: none"> Establish minimum compliance requirements for Revit content shared or sold throughout Australia and New Zealand. Document Revit content creation best practises. Establish a more extensive collection of shared parameters. Establish a list of object subcategories. Develop discipline-specific requirements for Revit content.
	NATSPEC	NATSPEC National BIM Guide	2011	To assist clients, consultants and stakeholders to clarify their BIM requirements for projects in a nationally consistent manner.
	Australia Mechanical Contractors' Association	BIM-MEP ^{AUS} Practice	2011	<p>Address the following barriers that are currently preventing the effective take-up and use of BIM within Australia:</p> <ul style="list-style-type: none"> Significant time and cost burdens involved in customising BIM modelling software to suit Australian design and construction requirements. Lack of industry standards around BIM MEP documentation. Poor consideration of the requirements for IPD. Limited BIM Project Management and file management expertise within the industry."
	Cooperative Research Centre for Construction Innovation	National Guidelines and Case Studies for Digital Modelling	2009	To assist in and promote the adoption of BIM technologies in the Australian building and construction industry, and try to avoid the uncertainty and disparate approaches that created inefficiencies with the implementation of 2D CAD over the past three decades.
USA	Massachusetts Institute of Technology Department of Facilities	MIT CAD & BIM Guidelines	2011	These guidelines are issued to promote the development of electronic drawings and models suitable for use in the MIT Department of Facilities CAD and BIM environment.
	Georgia Tech Facilities Management	Georgia Tech BIM Requirements & Guidelines for Architects, Engineers and Contractors	2011	<p>This document will allow all stakeholders to weigh the importance of each requirement on a per-project basis. Through this collaborative effort, a final project-based set of requirements and corresponding BIM Execution Plan will be issued based on what level of BIM proficiency necessary for a given project.</p>
	Indiana University Architect's Office and Engineering Services	BIM Guidelines & Standards for Architects, Engineers, and Contractors	2012	Standards for AEC.
	University of Washington Capital Projects Office	Attachment G - University of Washington CAD and BIM Standards	2012	Standards for A/E project drawings. This includes CAD and BIM drawing standards, PDF requirements, and the schedule of documents submittals for Owner's compliance review. The A/E may request a compliance review at any time during the Project .

USA	University of Southern California Facilities Management Services	BIM Guidelines	2012	Guidelines for design bid build contracts. This document defines the Design and Construction scope of work and deliverables for using BIM on new USC construction projects, major renovations and other projects as required by USC, based on a Design Bid Build form of Contract.
	Los Angeles Community College District	BIM Standard	2011	Standards for design-build projects. The LACCD BIM Standards for Design-Build Projects have been developed to define a process and establish requirements, procedures and protocol for the utilisation of BIM in the various stages of our design-build projects.
	San Diego Community College District	BIM Standards for Architects, Engineers & Contractors	2012	Standards for Architects, Engineers & Contractors The principle objective of incorporating BIM is to improve the quality of the design solutions and optimise the exchange of information between parties
	The Pennsylvania State University	BIM Planning Guide for Facility Owners	2012	Guide for facility owners. The Guide is written for facility owners who operate and maintain facilities, it can also provide value to those owners who procure facilities as well as other non-owner organisations wishing to adopt BIM.
	College of the Desert, California	BIM GUIDE	2011	Using Building Information Modelling for the design, construction, and management of all its future projects. This guide will cover the overall process of developing a BIM project workflow and the basic understanding of College of the Desert's standard.
	National Institute of Building Science buildingSMART alliance	National BIM Standard	2012	NBIMS establishes standard definitions for building information exchanges to support critical business contexts using standard semantics and ontologies...to be implemented in software
	United States General Services Administration	National 3D-4D BIM Program	2007	A guide "intended for GSA associates and consultants engaging in BIM practices for the design of new construction and major modernisation projects for GSA"
	American Institute of Architects	E202-2008 BIM Protocol	2008	This exhibit establishes the protocols, expected levels of development, and authorised uses of Building Information Models on this project and assigns specific responsibility for the development of each Model Element to a defined Level of Development at each Project phase. Where a provision in this Exhibit conflicts with a provision in the Agreement into which this Exhibit is incorporated, the provision in this Exhibit will prevail.
	Associated General Contractors of America	The Contractor's Guide to BIM	2009	to generally introduce the subject and provide an outline of the "how-to" for getting started
	United States Air Force Centre for Engineering and the Environment Capital Investment Management	"ATTACHMENT F" – BIM Requirement	2012	Requirement for design-build/firm fixed-price contract

USA

United States Army Corps of Engineers	Roadmap for Life-Cycle BIM	2012	The scope of this plan is to focus on the implementation of BIM in the U.S. Army Corps of Engineer's civil works and military construction business processes, including the process for working with the USACE Architectural Engineering Construction industry partners and software vendors
City of San Antonio Capital Improvements Management Services	BIM Development Criteria and Standards for Design & Construction Projects	2011	Standards for Design & Construction Project developed to define a process and establish requirements, procedures, and protocol for the utilisation of BIM in the various stages of CoSA's design and construction building projects elements and systems to use as a tool to more efficiently manage, maintain, and renovate the facility for the life cycle of the building
New York City Department of Design + Construction	BIM Guidelines	2012	The BIM guide considers the end-use of the model for multiple client agencies, allowing qualified and authorized client agency representatives to review the ways in which the BIM may facilitate their ongoing building operation and maintenance protocols, and tailor their agency requirement and standards to leverage the enhanced capabilities provide by BIM for building O&M.
New York School Construction Authority	BIM Guidelines and Standards for Architects and Engineers	2012	Guidelines and Standards for Architects and Engineers Use BIM and related software products as a tool, which would, amongst other things, assist in the development of coordinated Contract Documents for "Capacity" construction Projects
US Veterans Affairs	VA BIM guide	2010	This guidance shall apply to design and construction by the architects, engineers, other consultants, and contractors hired for those projects by VA.
The Port Authority of NY & NJ Engineering Department	EAD (E/A Design Division) BIM Standard Manual	2012	The Port Authority of NY & NJ BIM Standard Manual describes the processes and procedures required for the preparation and submission of BIM Models for Port Authority of NY & NJ projects.
State of Ohio Facilities Construction Commission	BIM Protocol	2012	<ul style="list-style-type: none"> Establish a common methodology for communicating owner's expectations for the level of detail and types of data contained in a building information model. Establish minimum building information modelling expectations that reflect current industry capabilities while incorporating processes that provide immediate value to owners. Encourage further industry adoption of BIM to allow owners to receive increased benefit from the technology
State of Texas, Texas Facilities Commission	Professional Service Provider Guidelines and Standards	2010	Guidelines and Standards for Architectural and Engineering This document applies to all TFC projects contracted on or after the Edit Date indicated in the header above.
State of Wisconsin Department of Administration, Division of State	DSF BIM Guidelines & Standards for ARCHITECTS and	2009	Guidelines & Standards for ARCHITECTS and ENGINEERS
Georgia State Financing and Investment	GSFIC BIM Guide Series 01: Model Analysis	2013	The purpose of this guide is to aid Architects and Engineers (A/Es) in their Building Information Modelling (BIM) efforts related to design and construction of GSFIC managed projects. This release –

Denmark	Erhvervsstyrelsen (National Agency for Enterprise and Construction)	Det Digitale Byggeri (Digital Construction)	2007	A guide made of 4 components: 3D CAD Manual, 3D Working Method, Project Agreement and Layer — and Object Structures
Spain	Generalitat Valenciana (Valencia Regional Government)	FIDE		Spanish
Finland	buildingSMART Finland	Yleiset tietomallivaatimukset	2012	The guidelines mainly focuses on architecture and engineer design.
	Senaatti Kiinteistöt (aka Senate Properties)	Senate Properties: BIM Requirements	2007	General operational procedures in BIM projects and detailed general requirements of BIM models — focuses on the design phase
Norway	Boligprodusentene	BoligBIM	2011	Intended to be a practical aid for those who perform the project planning for residential dwellings.
	Statsbygg	Statsbygg BIM Manual	2012	A ‘full-scale IFC test’ documenting experiences gained on a collaborative project
Netherlands	Rijksgebouwendienst (Ministry of the Interior and Kingdom Relations)	Rgd BIM Standard	2012	A BIM Framework consisting of seventeen orthogonal dimensions that describe in general the Building Information Modelling world constituting a "Way of Thinking about BIM"
United Kingdom	AEC (UK)	BIM Standard for AEC industry in UK	2011	It is aimed at providing a base starting point for a unified BIM standard that can easily be adopted “as is” or developed and adapted for implementation within projects that have specific requirements for the structuring of their BIM data. This document intends to provide platform-independent guidelines for BIM for designers.
	AEC (UK)	AEC (UK)BIM Protocol	2012	It focuses primarily on adaptation of those standards for practical and efficient application of BIM, particularly at the design stages of a project
	Construction Industry Council	Best Practice Guide for Professional Indemnity Insurance when using BIM and, Outline Scope of Services	2013	The aim of this best practice guide is to support the construction industry’s take up of Level 2 Building Information Modelling, by summarising the key areas of risk which Professional Indemnity (‘PI’) insurers associate with level 2 BIM and what you can do about those risks as a prudent insured.
	Specialist Engineering Contractors’ BIM Academy at the University of Northumbria. National Specialist Contractors’ Council	First Steps to BIM Competence: A Guide for Specialist Contractors	2013	The purpose of this guidance document is to acquaint firms with the steps they need to take to become comfortable using Level 2 BIM – that is, developing and sharing project-related data in a 3D format with other parties.

Singapore	Building and Construction Authority	Singapore BIM Guide	2012	It is a reference guide that outlines the roles and responsibilities of project members when using Building Information Modelling (BIM) at different stages of a project. It is used as a reference guide for the development of a BIM Execution Plan, which will be agreed between the Employer and project members, for the successful implementation of a BIM project.
	CORENET e-submission System	CORENET BIM e-submission Guidelines	2010	Architectural, structural and MEP guidelines were published
Hong Kong	The Hong Kong Institute of Building Information Modelling	BIM Project Specification	2011	This BIM Standard is intended to be used to define the scope of work for a BIM process, the responsibilities of the project participants and the deliverables from the BIM Process for the overall benefit of the project and the owner.



Appendix B – Existing BIM Tools

Tool	Vendor	Capabilities
Revit	Autodesk	<ol style="list-style-type: none"> 1. Including Revit Architecture, Revit Structure and Revit MEP; 2. Parametric components: Use intelligent building components to improve design accuracy; 3. Bidirectional associativity: Any change in your design is automatically reflected throughout your model; 4. Work-sharing: Multiple users can simultaneously work on the same intelligent building model; 5. Construction modelling: Improve insight into constructability of building elements.
AECOSim	Bentley	<ol style="list-style-type: none"> 1. Including Architectural Design, Structural Engineering, Mechanical Engineering and Electrical Engineering; 2. Interdisciplinary modelling environment to integrate design and documentation workflows, eliminate barriers between disciplines, and shorten learning curves; 3. Immersive interaction to create and interact with 3D models, 2D designs, as well as innovative hyper modelling to integrate and access all available project information; 4. Trusted deliverables production to generate precise drawings and documentation, information-rich 3D PDFs, and 3D plots; 5. Performance simulation to evaluate and explore designs through lifelike rendering and animation, generative design, and built-in clash detection; 6. Comprehensive breadth and depth to integrate engineering geometry and data, including point clouds, from an unmatched range of CAD and BIM software and engineering formats like IFC and DWG
ArchiCAD	Graphisoft	<ol style="list-style-type: none"> 1. Priority Based Connections; 2. Industry-first Background Processing; 3. Extended IFC Model View Definitions; 4. Open Interface to External BIM Component Providers; 5. Integrated Design, Visualisation and Analysis Workflow
Tekla Structure	Trimble	<ol style="list-style-type: none"> 1. For Concrete Contractors: Model, plan and pour concrete; 2. For Steel Fabricators: Manage detailing, fabrication and erection of all steel structures; 3. For Precast Fabricators: Optimise the entire precast workflow from bidding to delivery; 4. For Electricity Utilities: Manage electricity networks and perform multiple distribution process; 5. For Rebar Fabricators: Manage prefabrication of rebar and reduce total cost and time.
SketchUp Pro	Trimble	<ol style="list-style-type: none"> 1. Start by drawing lines and shapes, push and pull surfaces to turn them into 3D forms; 2. Changes to your model are reflected automatically in Layout; 3. Having the world’s biggest repository of free 3D models; 4. Massive plugins provide extra features such as sustainable analysis.
Digital Project	Gehry Technologies	<ol style="list-style-type: none"> 1. Including Designer, Manager and Extensions; 2. Designer: Generative surfaces design, Parametric 3D surfaces, Free-style surface modelling (NURBS), Design to fabrication, Revision tracking and part comparison, and Advanced solids modelling; 3. Manager: Real-time sectioning, Measure object dimensions, Quantity take-offs, Access volume measurements, and Project team collaboration; 4. Extensions: Import Primavera activities, MEP/Systems routing, 3D models for curved shapes, Advanced parametric control, and STL and STEP integration.

Rhino	Rhinoceros	<ol style="list-style-type: none"> 1. Editing complex models is faster and easier with “Direct sub-object manipulation” and “Thin-wall shelling”; 2. Easier to create 2D drawings and illustrations for every discipline in every notation system and visual style used around the world; 3. Rhino models can be accurate enough for and accessible to all the processes (e.g. fabrication, manufacturing, or construction processes) involved in a design becoming a reality; 4. Robust mesh import, export, creation, and editing tools;
Catia	Dassault	<ol style="list-style-type: none"> 1. 3D Design : Industrial design, Class A, Reverse Engineering; 2. Mechanical Engineering: Optimising end to end design to manufacturing process; 3. Electrical & Fluid Systems Design: Managing product complexity; 4. System Engineering: Bringing products to life; 5. Experience Modelling: Providing clear dashboards, powerful analysis capabilities, and flexible searching.
E3D	AVEVA	<ol style="list-style-type: none"> 1. Design solution: Multi-discipline 3D plant design, Intuitive 3D graphics, User-friendly interface, Local Customization; 2. Reduce business risk: Multi-discipline 3D plant design, Built-in quality and compliance; 3. Integration: Built-in quality and compliance, Integrated 3D, engineering and schematic data; 4. High Performance: Integrated 3D, engineering and schematic data, High performance in large networks.
PDMS	AVEVA	<ol style="list-style-type: none"> 1. A fully interactive, color shaded 3D plant design environment, Hundreds of designers can work concurrently on a project ; 2. Designers progressively create a highly intelligent 3D design by selecting and positioning parametric components from an extensive catalogue; 3. Clash checking and configurable integrity checking rules ; 4. A configurable Status Management function provides visual highlighting and clear reporting of design maturity status of PDMS objects; 5. Highly configurable, automatic generation of a wide range of reports and drawings direct from the PDMS database ; 6. AVEVA PDMS is highly configurable and includes both a powerful programmable macro language (PML) and a .NET API to customize the system and automate tasks.
SmartPlant Enterprise	Intergraph	<ol style="list-style-type: none"> 1. 3D Modelling & Visualisation : Providing an integrated design environment for plant construction to save project time and increase production efficiency; 2. Engineering & Schematics : Designed to drive plant optimisation, the rule-driven environment prevents engineering errors for increasing data quality and consistency across tasks; 3. Information Management : maximizes efficiency for industrial and manufacturing plant maintenance and provides plant operation solutions; 4. Procurement, Fabrication & Construction : materials specification and change management through procurement and tracking to inventories, forecast, and material issuing. Intergraph lowers labour costs throughout engineering, procurement, and plant construction; 5. The SmartPlant Enterprise family includes 27 products for the specific project purpose.

12D Model

12D

1. 12d Model is a powerful terrain modelling, surveying and civil engineering software package.
2. It allows quick and high quality production in a wide variety of projects including: Road and Highways, Ports and Dredging, Land Development, Airport Infrastructure Rail, Mining Infrastructure, Drainage, Sewer and Utilities Surveying, Oil and Gas, Construction Rivers, Dams and Hydrology Environmental
3. Using 12d Model's screen menus and fast interactive graphics, the user effortlessly moves through a design.
4. With 12d Model's powerful design capabilities, difficult surveying and civil design tasks can be easily visualised and completed.
5. 12d Model includes a powerful programming language, which allows users to build their own options, from the extensive 12d Model programming library.
6. 12d Model has been specifically designed for easy use. It is ideal for use at all stages of projects, and is particularly useful for large route selection and corridor studies.



Existing 4D Simulation Tools

	Vendor	Capabilities
Navisworks	Autodesk	<ol style="list-style-type: none"> 1. Simulate 4D construction schedules and logistics; 2. Generate object-oriented animation; 3. Develop compelling 3D animations and imagery.
ConstructSim	Bentley	<ol style="list-style-type: none"> 1. Comprehend the full complexity of modern construction projects during initial planning through the Virtual Construction Model; 2. Improved constructability analysis and advanced planning and coordination between engineering office and site field office; 3. Design out unsafe construction practices; 4. Reduce time to create work packages while increasing accuracy; 5. Ability to match available labour to work packages; 6. Support Agile/Lean/WFP construction methods; 7. Plan ahead to reduce construction bottlenecks; 8. Reduce rework and out-of-sequence work; 9. Streamline turnover and commissioning planning.
Synchro	Synchro	<ol style="list-style-type: none"> 1. Enable full round trip data synchronization (Import, Export, Synchronize To and From) to facilitate work flows for both upstream and downstream delivery processes; 2. 4D spatial coordination for static and dynamic analysis and conflict resolution; 3. Deliver traditional project scheduling, reporting, custom 4D animation, advanced AVI production; 4. Provide EVA (earned value analysis) and cost loaded schedule for including variable cost analysis for decision support and for planned and actual cost analysis; 5. Database module enables advanced systems integration, reusable project and component libraries, and support for the ever increasing data in the BIM model to enterprise data management envisioned by the industry.
Vico	Trimble	<ol style="list-style-type: none"> 1. Locations are used to perform location-based quantity takeoff which is the input for location-based schedule planning; 2. Adopting flow-line scheduling to optimise the construction schedule; 3. On-site production control: Measuring work put in place by location and comparing actuals to planned helps Supers see potential conflicts far in advance; 4. 4D BIM scheduling movies makes it easy for audiences (Owners, trades, teams) to see how the building will come together.
DELMIA	Dassault	<ol style="list-style-type: none"> 1. Plan, with comprehensive 3D process and resource planning tools to create and optimise build-to-order and lean production manufacturing systems; 2. Simulate, with tools to virtually define and optimise manufacturing assets concurrently with manufacturing planning; 3. Operate an accurate virtual production system to track real-time production activities, perform schedule changes, launch new programs and introduce model changeovers, and schedule maintenance operations.
NET Player	AVEVA	<ol style="list-style-type: none"> 1. Easily understood display of project status and construction sequence via the 3D model for monitoring critical tasks; 2. Simulation and review of construction sequences in 4D; 3. Playback controls enable the user to start, stop, loop and step through the animation; 4. Rrapid compilation of production or construction progress and status reports.

Existing 5D Simulation Tools

	Vendor	Capabilities
Navisworks	Autodesk	<ol style="list-style-type: none"> 1. Simulate 5D construction schedules and logistics; 2. Model-based quantity takeoff.
iTWO	RIB	<ol style="list-style-type: none"> 1. Combine traditional construction planning and trail-blazing 5D planning in one software suite; 2. Resource control through all project phases with end-to-end visual support; 3. Construction Process Integration heralds a new quality in the planning and building process; 4. Making important information transparent and complex contexts manageable.
Vico	Trimble	<ol style="list-style-type: none"> 1. Location-based construction-caliber quantity take-off; 2. Project stakeholders can examine budget levers, the items which greatly influence a project's ability to stay on track and run powerful comparisons.
CostX	Exactal	<ol style="list-style-type: none"> 1. Support 5D BIM using information from the model live-linked to user-defined rate libraries and workbooks- all within the one program; 2. A networked environment allows instantaneous information sharing with others working on the server; 3. Import of a multitude of drawing files and external rate information, and exports to a variety of formats, taking interoperability to a new level; 4. Unique revision tool identifies changes and automatically updates quantities; 5. Use in-built templates to import model data or easily create Model Maps to customize your BIM take-off.
Innovaya	Innovaya	<ol style="list-style-type: none"> 1. Automatic Quantity Extraction and Estimation; 2. Intelligent Assembly/Item Take-off; 4. Completely Embracing MC2 and Timberline Estimating; 5. Intelligent Change Management; 6. Support for Effective Team Communication.

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Printed April 2017