CORE2018 CONFERENCE ON RAILWAY EXCELLENCE
Rail: smart, automated, sustainable RTSA

Digital starting blocks: The Sydney Metro experience

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SUMMARY

Sydney Metro is currently Australia's biggest public transport project. Stage 1 and 2 of this new standalone railway will ultimately deliver 31 metro stations and more than 66 kilometres of new metro rail, revolutionising the way Australia's biggest city travels. Once it is extended into the central business district (CBD) and beyond in 2024, metro rail will run from Sydney's booming North West region under Sydney Harbour, through new underground stations in the CBD and beyond to the south west.

Sydney Metro City and Southwest (Stage 2) features twin 15.5km tunnels along with 7 new underground stations between Chatswood and Sydenham. The line is extended beyond Sydenham with an upgrade of the existing Sydney Trains heavy rail line to Bankstown.

The adoption of a digital engineering approach on the Sydney Metro City and Southwest project resulted in an unprecedented level of collaboration and engagement between designers, clients and stakeholders.

The use of tools such as WSP's bespoke web based GIS spatial data portal Sitemap allowed geographically mapped data to be made securely available to all stakeholders involved on the project, enabling the team to work off a common data set while simultaneously controlling/restricting access to sensitive data. Over the course of the project this portal was enhanced to act as a gateway to all other digital content developed for such as live digital design models, virtual reality and augmented reality content. This portal was the prototype for what is now called 'WSP Create'. WSP Create is the digital platform for WSP's projects going forward and allows partitioned access to all project specific digital content from GIS through big data analytics and visualisations.

Digital engineering allowed the Sydney Metro City and Southwest project team the ability to aggregate, host and access one version of design truth but also to transform and convey this data into a visual format that supported and communicated decisions early in the design phase.

This paper shares some of the key facets of the approach WSP took in coordinating and using the large volumes of data in the design for the project. It explores how digital design tools were used to streamline the process of design approvals with client, Transport for NSW, and create a common understanding and vision of design with stakeholders across the board. It also discusses the evolution of these tools and their applicability in the context of Sydney Metro West, the next major railway infrastructure investment in NSW.

1 INTRODUCTION

1.1 Project Overview

The Sydney Metro program forms part of the NSW Government's response to Sydney's continued employment and population growth.

Sydney Metro Northwest (Stage 1) is currently under construction and will begin operation in 2019. It comprises a 36km Metro line that will service the community between Rouse Hill and Chatswood with 8 new stations and an upgrade of the existing 4 stations between Epping and Chatswood.

This paper is focussed predominantly on Stage 2 of the program, Sydney Metro City and Southwest which features twin 15.5km tunnels along with 7 new underground stations between Chatswood and Sydenham. The line is extended beyond Sydenham with an upgrade of the existing Sydney Trains heavy rail line to Bankstown to prepare it for Metro operations.

For procurement purposes, Stage 2 has been separated into a number of key packages that are at varying stages of development:

- Chatswood to Sydenham tunnels and station civils (TSE)
- Underground Station Design and Technical Services (USDTS)
- Demolition works
- Sydney Yard Access Bridge (SYAB)
- Southwest Sydenham Junction (SSJ)
- Central Station Main Works (CSM)
- Southwest Stations and Civils (SSC).

Sydney Metro West will form the next railway infrastructure investment in Sydney following the completion of Sydney Metro Stage 1 and 2. Planning and identification of the number and

location of potential stations for Sydney Metro West commenced in October 2017.

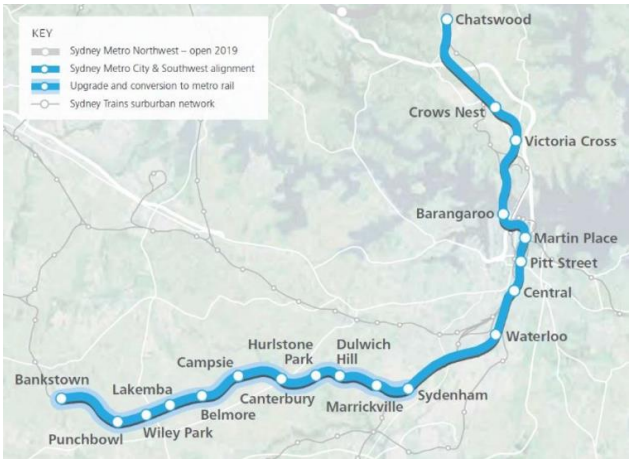

Figure 1 City and Southwest Route Map

Transport for NSW engaged the design joint venture (DJV) of WSP and AECOM, with architectural support from Cox and HASSELL together with constructability support from Rail Planning Services as Technical Advisor for the Sydney Metro Stage 2 works.

The technical advisor role included:

- site investigation, management and interpretation
- alignment development, station arrangement and connectivity design, constraints mapping and risk assessment
- tunnel engineering, including tunnel services and ventilation
- station engineering and architectural study
- rail system design
- brownfield and greenfield constructability
- constraints assessment and impact assessment
- preparation of reference design and contract documentation.

The key objectives of the DJV included:

- Developing and protecting a metro alignment through the heavily constrained CBD and North Sydney environments, confirmation of property requirements and managing risk.
- Ensuring a constructible solution with cost and program certainty that balances station functionality and property acquisition, worksite/rail corridor access and construction efficiency
- Facilitating the environmental approvals process
- Driving the seamless integration across the Northwest and City & Southwest projects through the application and augmentation of systems and processes, management of contract and physical interfaces and ensuring consistency of product and vision.
- Enabling innovative design solutions, fully resolved and integrated, offering value for public money to a level of design tailored to the procurement strategy

In October 2018, Transport for NSW engaged a similar DJV of WSP and AECOM, this time in partnership with architectural firms Cox, Woods Baggot and Farrells as Technical Advisor for the Sydney Metro West Scoping and Definition Design works.

2 DIGITAL ENGINEERING APPROACH

The digital engineering approach adopted on Sydney Metro City and Southwest centred around the use of specific digital tools and methodologies including:

- data aggregation and formation of digital baseline content
- virtual and augmented reality as design decision making tools
- web based GIS for secure anytime access to project information

A similar approach is being rolled out and further developed on Sydney Metro West.

2.1 Data Aggregation

The digital engineering approach adopted on Sydney Metro City and Southwest was focussed on the alignment of digital information systems including CAD, GIS, BIM, construction staging and cost data, electronic document management systems and existing asset data. Adhering to a BIM Level 2 workflow, the project used federated models to fundamentally support design development and coordination. These models consist of both 3D geometrical elements/components and non-graphical data.

Through the application of BIM platforms such as Revit and Navisworks the DJV produced 3D coordinated station models covering architecture, MEP and structures design along with extensive 3D mapping of critical constraints information. The discipline specific models were aggregated in the project federated models. These were then made available to the wider team for reference and interrogation providing a complete picture of the current design status in the context of relevant constraints.

For the brownfields sites on the project, federated models were created using data captured by the project surveyors using oblique airborne photogrammetry. This technology is used to rapidly develop 3D context models. The photorealistic and geographically accurate 3D models provide authentic context information and above ground constraints data. The information is also provided

in an editable format for designers and modellers, making it more functional than conventional LiDAR.

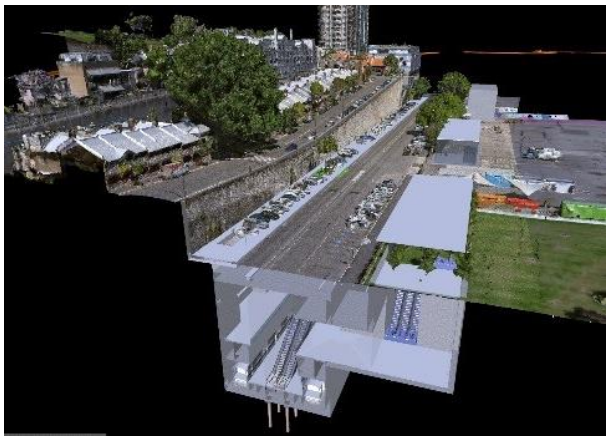

Figure 2 Sectioned federated model with 3D context data

2.2 Virtual and Augmented Reality

The use of virtual reality (VR) technology as a design tool was another aspect of digital engineering the DJV implemented and developed on Sydney Metro. VR was used to allow fast paced design decisions and communication of complex 3D issues, options/scenarios and problems. Traditionally, the adoption of VR has been limited by cost and technology shortcomings and production time. Recent developments have seen these barriers removed with the availability of simple to use and accessible applications and hardware. The project saw the quick and efficient publication of immersive VR data by leveraging the BIM design approach and methods of making data widely available.

Augmented Reality (AR) was used to overlay design information in true context to aid client and stakeholder appreciation of proposed designs in highly constrained locations. Application of this technology has enabled project staff to view conceptual 3D design models within existing brownfield environments. Using tablets with GPS, gyroscopes and real time cameras, this enabled a way of virtually experiencing the planned new works long before construction.

Mixed Reality (MR) technology was prototyped to allow multi-user interaction with design models and context information.

Figure 3 Augmented reality on site

2.3 Web Based GIS

The adoption of WSP's web based GIS portal SITEMAP allowed geographically mapped data to be made available securely to all project participants and stakeholders anywhere, anytime and on any device with web access. The use of SITEMAP is further discussed in the following sections.

3 SITEMAP DEVELOPMENT

At the commencement of Sydney Metro City and Southwest in September 2014, establishing a web GIS portal for the project was identified as a critical element in our overall digital approach. The GIS was initially setup to absorb and make available to the design team, constraints and proposed alignment/station design information. Subsequently the GIS transitioned into a platform for design information and other digital content to be shared with the wider project team.

SITEMAP is a mapping portal developed by WSP. The portal can be configured to allow access to any number of applications, each ranging purpose, functionality and appearance including map layers. SITEMAP is a javascript and ASP.NET application built upon ArcGIS Server, ERDAS APOLLO, Geoserver and SQL Server in the backend. The portal is hosted by WSP in our Sydney based server environment. Developing and maintaining a web GIS was not initially identified by the client as a project requirement. However, the complexity of the project and the high number of complex interfaces drove this decision by the team to adopt the platform.

3.1 Contract Information Management and Procurement

The ability to make available data to a broad stakeholder population is critical in the success of a project as big as Sydney Metro City and Southwest. SITEMAP was used to supplement the client mandated electronic document management system (EDMS) TeamBinder. TeamBinder was used for published information and formal project communications whilst SITEMAP, together with the federated BIM models provided shared information to the client and a wide range of their approved service providers, including technical advisors for:

- program and cost planning
- planning approval (Chatswood to Sydenham)
- planning approval (Sydenham to Bankstown)
- spatial survey and property
- geotechnical site investigations
- services investigations
- shadow operations
- asset condition assessment
- oversite development.

As the developers and maintainers of SITEMAP, we worked closely with the client to provide a platform that considered sensitive issues around security and access to certain datasets. This saw the emergence of what was referred to as project 'instances'. An instance is a mini site or application that sits within the main portal. The purpose of each instance is to partition data aligned with procurement and probity requirements. This enabled us to make available common datasets whilst also controlling/restricting access to sensitive data. Based on a participant's role on the project, they were granted access to relevant instances via an individual user login. In addition to being able to draw down on important project information, users are also able to save mark-ups and prepare figures themselves. The use of SITEMAP proved to be integral to the process of collaboration and communications across the project team.

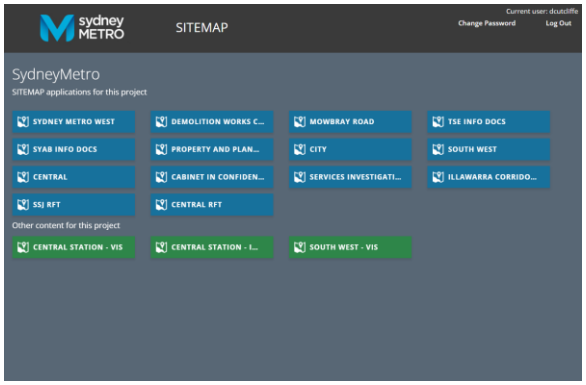

Figure 6 SITEMAP user homepage

A number of instances were prepared for specific delivery contracts to make available information to expression of interest registrants and tenderers. Common logins were provided to third parties via formal communications from the client and the instances remain static to ensure no updated information was provided without notice during a tender period.

By mid-2017, a total of 325 user accounts had been issued across a number of organisations. Whilst over half of this total is staff from the design technical advisor, as the design phase was completed, the client and third party user group continued to grow reflecting the wider uptake of the SITEMAP tool. A total of 25 organisations were issued accounts to the Sydney Metro SITEMAP over the course of tendering and procurement.

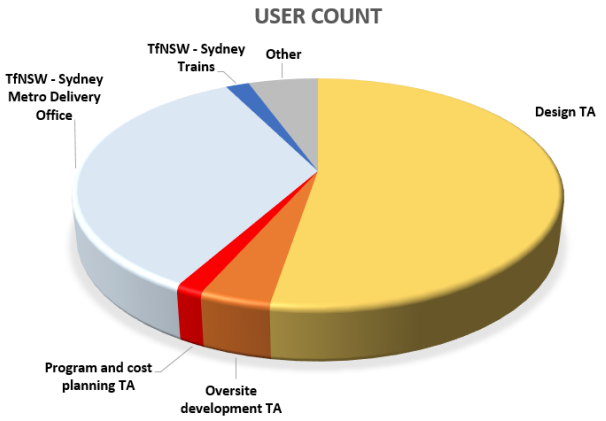

Figure 7 SITEMAP users by organisation

Specific applications of SITEMAP are outlined in the following sections however in addition to serving out traditional GIS information, the SITEMAP portal was enhanced over the course of the project to act as a gateway to all other digital content developed for the project such as live digital design models, virtual reality and augmented reality content.

This development was the prototype for what is now called 'WSP Create'. WSP Create is the digital portal used for delivering digital engineering content to WSP projects. Based on the SITEMAP application, the portal allows partitioned access to all project specific digital content from GIS, BIM models, big data and business analytics and visualisations.

A project specific version of WSP Create has been rolled out on Sydney Metro West and will be used to host and make available all digital content produced over the course of the Scoping and Definition Design Phases.

3.2 SITEMAP Services Mapping

In addition to supporting multi-disciplinary design activities, SITEMAP was used to meet key requirements with respect to public utility services. With the extensive tunnelling and significant excavation work proposed as part of the project, the identification and mapping of existing services and their proposed treatments/diversions was highlighted as a critical input into the design. The DJV gained access to a wide range of existing GIS asset data from public utilities, councils, and Transport for New South Wales (TfNSW) operators and interfacing projects. Leveraging the experience of our Geospatial Team on similar projects and utilising functionality already developed, SITEMAP was setup to enable our designers to input directly into a spatial database.

Designers utilised this platform as a tool to tag and 'mark-up' assets in a working environment. This information was then captured online in the mark-ups database and attributed to the user responsible. This facilitated the designers' development of proposed treatments and diversions to existing services whilst building a database of detailed information relating to each.

Following robust coordination and verification, the data was then published to a static mapped services layer. This mapped information was then consumed by the wider project team, making it quick and easy for stakeholders to access and reference important data. Common to any urban environment, there is a high density of existing services in the CBD of Sydney including heritage listed oviform water mains and the Telstra tunnel network. Due to the sensitivity and risk associated with negatively impacting these assets, ensuring the designers could easily reference the latest data was imperative. Existing drawings and documents sourced from utility companies were included in the mapped services database and made available on SITEMAP via attributed web hyperlinks.

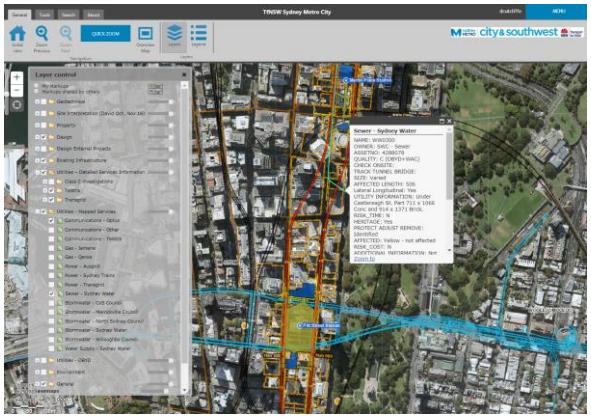

Figure 4 SITEMAP identification of mapped services

Once mapped services information was captured in the geodatabase, ArcGIS was used as the tool to prepare the final drawing deliverables. The project realised efficiency gains from this approach as information transfer and presentation using a CAD platform is traditionally a time-consuming process. The use of GIS resulted in easy and cost effective publication of this information for combined services, service types/groups, and for individual utilities such as Sydney Water, Telstra, and Ausgrid.

In addition, the mapped services layers were also referenced into CAD software from the geodatabase and used to develop a 3D constraints model at each major site. The DJV used a risk based approach to the 3D modelling of existing services, prioritising sensitive assets to inform the station design development. The services modelled in CAD followed a common classification protocol. An example of the application of this information was in the design of high level pedestrian tunnels in the CBD and managing the associated complex interfaces with existing sensitive services. Federated models were used to demonstrate the coordinated design and interface with existing assets.

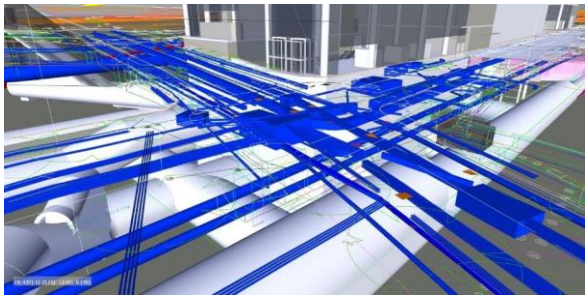

Figure 5 Federated model with existing services

3.3 Sydney Trains Interface Management

The delivery of design, constructability and staging solutions cognisant of the complex existing network condition, operations and maintenance, formed a significant challenge for the project. SITEMAP was used to capture and make available to the project team geospatial data provided by Sydney Trains for several key brownfield interface areas including:

- The Sydney Metro Chatswood dive structure and tunnel portal which requires significant enabling works to the existing rail corridor; this includes temporary realignment of the T1 North Shore Line and permanently closing an existing road overbridge.
- Constructing a new rail underbridge for a section of the final alignment of the northbound T1 North Shore Line to pass over the metro northern dive structure.

- Realigning the T1 North Shore Line within the existing rail corridor between Chatswood Station and Artarmon.
- Removal of existing and addition of new corridor access points.
- A new underground pedestrian link between the T4 Eastern Suburbs and Illawarra Line platforms at the existing Martin Place Station.
- Construction of the new metro platforms at Central Station requires the area around the existing platforms 13, 14 and 15 and between the suburban and country lines to the south. This site includes the footprint of the new underground metro platforms and forms part of the existing Central Station operational area.
- A new access bridge from Regent Street into the rail corridor (Sydney Yard). This will provide construction and operational maintenance access for both Sydney Metro and Sydney Trains.
- Building a temporary pedestrian bridge at Central Station.
- Adjusting rail systems around platforms 13, 14 and 15.
- Adjusting rail systems around platforms, the paid pedestrian connections and Devonshire Street tunnel.
- Sydenham Station upgrade and junction works; this includes the relocation of major stormwater channels and aqueduct across Sydenham Pit and associated civil and structural work to enable separation between Sydney Trains and Sydney Metro operations.
- 13.5km upgrade and conversion of the T3 Bankstown Line to metro standards, including the upgrade to all existing stations.

Sydney Trains Detailed Site Survey 'DSS', typically provides a highly detailed map of the complex internal sub-surface utility network within the rail corridor. The feature data is collected via field surveys and is then prepared (and controlled) as CAD files and GIS. The DSS coverage across the network is not fully comprehensive and historically projects have only been provided with CAD files.

The Sydney Metro City and Southwest project team engaged with the Sydney Trains Asset Information Services Team (AISS) to gain access to information from their network infrastructure geodatabase. This data was provided as an export from Sydney Trains together with associated metadata, and was then aggregated into our working system and made available in SITEMAP to the project team as required.

Consideration was given to the option of Sydney Trains providing this data via a live web service that could be made available in SITEMAP. At a technical level, it was agreed in principal by both parties that this was a desired objective, however this proved difficult to execute with respect to timelines for approvals.

Easy access to this comprehensive geospatial data provided a deeper level of understanding into the existing network for designers and the wider project team. In addition to the typical DSS CAD information including route types, service groups and location, the Sydney Trains Infrastructure GIS included additional asset data attributed to spatial features. This was particularly useful when it came to identifying and referencing HV distribution and traction power cables in areas impacted by proposed new works.

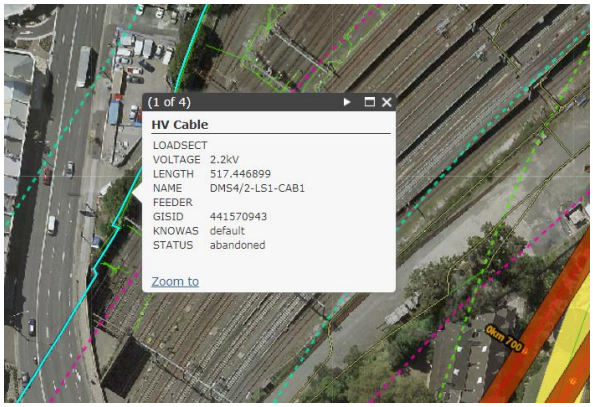

Figure 8 Sydney Trains Infrastructure GIS data

3.4 Asset Information Management

Whilst there are several significant interfaces with the existing Sydney Trains network spanning the City and Southwest project, the conversion of the Bankstown Line to metro operations was particularly sensitive with respect to existing asset condition and liabilities.

As part of the information sharing agreement developed, Sydney Trains provided exports from their Ellipse Asset Database and Discrete Asset Database for relevant areas. Gaining access to this data enabled the identification of existing assets and asset maintenance planning associated with the Bankstown Line. This baseline Ellipse data was geocoded to enable mapping and inclusion in SITEMAP.

Sydney Trains also made available geocoded front of train imagery captured as part of their mechanised track patrol (MTP) program which forms part of their infrastructure GIS.

3.5 Asset Condition Assessment Data

With significant works proposed at Central Station and the existing corridor between Sydenham to Bankstown, Transport for NSW commissioned asset condition assessment surveys for these areas to supplement existing asset information.

Major existing civil assets assessed included bridges, tunnels, embankments, formation & ballast, cuttings, drainage, retaining walls, utilities and station platforms. Both Central Station and the Bankstown Line were originally constructed over 100 years ago and have seen ongoing changes, development and the replacement of life expired infrastructure over their lifecycle.

The information gathered assisted in identifying imminent and ongoing maintenance/replacement requirements to enable safe operation of the Sydney Metro. This was mainly in relation to existing asset condition, likely reliability, impact on the performance of metro operations, likely future renewal needs and anticipated on-going maintenance requirements.

Figure 9 Formation assessment at Central Station

A key requirement as part of the scope of the asset condition assessment (ACA) contract was preparation of the data in a geodatabase. Specific data format requirements outlined in the contract allowed for the information captured by the ACA technical advisor to be seamlessly integrated into SITEMAP. In addition to the native geodatabase delivery, the technical advisor furnished a standalone viewer; this enable the data to be reviewed as a deliverable in isolation.

4 VIRTUAL REALITY AS A DESIGN TOOL

The use of virtual reality (VR) on Sydney Metro City and Southwest allowed the transformation of complex design data into a visual format. VR was used to help inform design decisions and communicate complex 3D issues, options, scenarios and problems to the client, their stakeholders, and the wider project team at the front end of the design life cycle.
Developments in technology and the incorporation of robust BIM design workflows early in the design process made it simpler to prepare VR content and experiences. Coupled with the introduction of VR ready hardware such as fixed and mobile VR headsets together with tablets allowed the easy adoption of VR as an integral part of our overall design approach.

4.1 The Virtual Reality Spectrum

The VR spectrum is the term used to describe the range of detail and effort associated with preparing VR content and experiences. ‘White card’ models are prepared quickly and easily as an output from the BIM workflow and feature a low level of rendering. This VR content and experience is an effective tool when used as part of the ongoing design process and can help to communicate design intent and issues to the immediate project team. Highly rendered or ‘high end’ models feature a greater level of realism and are produced for more focussed communications purposes, including client and stakeholder engagement and the production of final design deliverables and presentations.

Key design applications of VR on the project included:

- Evaluation of more human design factors such as aesthetics, functionality, ease of use and quality of space prior to translation of these requirements into a specification.
- Exploring and testing of design decisions with quick insight into scale, proportion and spatial interaction allowing quick iteration through options (e.g concourse head heights and front of house spaces).

Key communications and interface management applications of VR on the project included:

- Engagement in the design on a more visceral level leading to higher levels of engagement.

- Communicating and building excitement for the station designs with stakeholders prior to construction commencing.
- Immersive experience of design solutions early in the design phase including pedestrian walk throughs.
- Allowing key stakeholders to 'experience' the design and assess how it achieves their requirements rather than gauging this from traditional 2D drawings or 3D models or 3D models.
- Allowing virtual prototyping early in the design process.
- Clash detection and communication.

Figure 10 Use of VR for stakeholder engagement

Historically the more 'high end' VR productions and experiences have relied upon a mix of 2D and 3D data – this often meant that there was a lot left up to interpretation, thus leading to a product not always aligned with the intended outcome. By working in a full 3D environment producing the 'high end' product is now simplified and more cost effective. It is simply a case of identifying the experience and detail required, then matching the platform, rendering and graphics needed to fit the purpose.

4.2 Mapping Published VR Content

As mentioned earlier, published 360-degree VR content was mapped to SITEMAP, enabling staff away from the technical/BIM production environment to experience the design as it was developed. The content was geolocated and established in a separate instance for consumption by approved staff via web access. This allowed easy navigation/ orientation and any time access to the VR content and was design to support a variety of devices including laptop, desktop, tablet or phone. Mobile devices with inbuilt gyroscopes meant users could easily interact with the 360-degree renders. Mobile phones were also used in conjunction with VR headsets to provide full immersive experiences teleporting the user into the station designs. As the designs progressed and became more complex, the availability of this VR content proved increasingly important in the engagement of stakeholders and the level of design appreciation help by the project team.

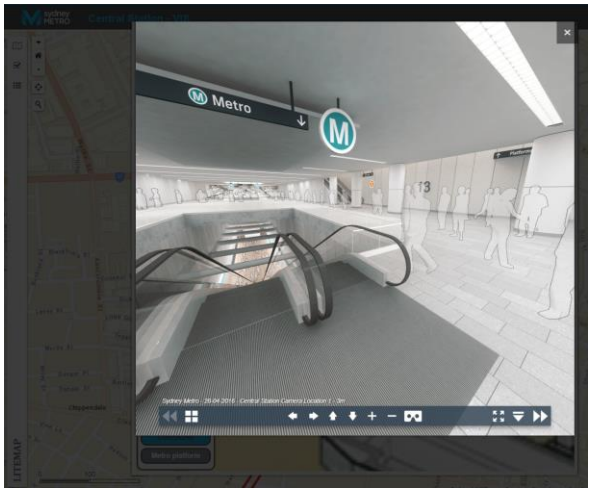

Figure 11 VR content mapped to SITEMAP

5 AUGMENTED REALITY

Augmented Reality (AR) technology was used in the assessment of the visual impact associated with design solutions specifically in the existing brownfields rail environment. AR content was prepared for a number of sensitive site locations including specific station locations along the Bankstown line, for particular elements at Central Station and around the proposed Barangaroo Station site. The models provide actual context to the designs and allow stakeholders to experience the design through choosing their desired perspective.

Figure 12 Tablet image from AR site experience

The use of AR on-site proved particularly useful in the engagement of key stakeholders whose ordinary appreciation of the design is not comprehensive. This application of AR also

challenged the conventional approach of having to prepare desktop photo montages from fixed locations for community engagement and environmental planning purposes.

6 CONCLUSION

The result of focused effort and maintaining an emphasis on aggregating and mapping data into a single source led to the development of a highly reliable platform used by hundreds of project staff. SITEMAP and VR technologies were recognised as invaluable project resources by a wide range of users on Sydney Metro City and Southwest as a tool to securely store project information and support and enhance collaboration and communication.

On complex linear infrastructure projects such as Sydney Metro, the importance of robust spatial data management cannot be discounted. The project realised benefits in the form of time savings via improved information sharing, collaboration and communications by combining BIM and GIS technologies.

As the technical advisor working closely with the client and interfacing organisations at the early stages of development, it is vital that asset data is treated as a valuable resource. The organisation and availability of this information as the design develops is an important feature of the technical advisor role.

The application of digital engineering at the early stage of design established a legacy for the project as it heads into the delivery phase. In the provision of SITEMAP to the broader project as part of our service, we have demonstrated that a collaborative approach to delivery can add value throughout the design lifecycle.

The following is a testimonial provided by the clients Technical Services Manager Steve Myers:
The development and management of the SITEMAP spatial tool for Sydney Metro City & Southwest by WSP has provided the project with an invaluable asset to manage a wide spectrum of data pertinent to the wider project. SITEMAP has facilitated configuration management of important data sets, data sharing within the project team and amongst the wider stakeholder community, Service Providers and Contractors. SITEMAP has provided a common understanding of the knowledge base available and facilitated a cooperative approach, especially for the all too important interfaces between disparate organisations.

7 ACKNOWLEDGEMENTS

The authors would like to thank the client, TfNSW, Sydney Trains and all the participating organisations for sharing data and engaging with our platform for project collaboration.

Our DJV partners on the Sydney Metro City and Southwest project, AECOM, Cox, HASSELL, and Rail Planning Services, together with all our sub consultants.

Our WSP geospatial and visualisation team, without whom none of these positive outcomes would have been achieved, particularly our leads:

- Michael Sparrow, Principal Visualisation Consultant
- Gustaf Jonsson, Principal GIS Consultant
- Ashley Trinder, Principal GIS Consultant