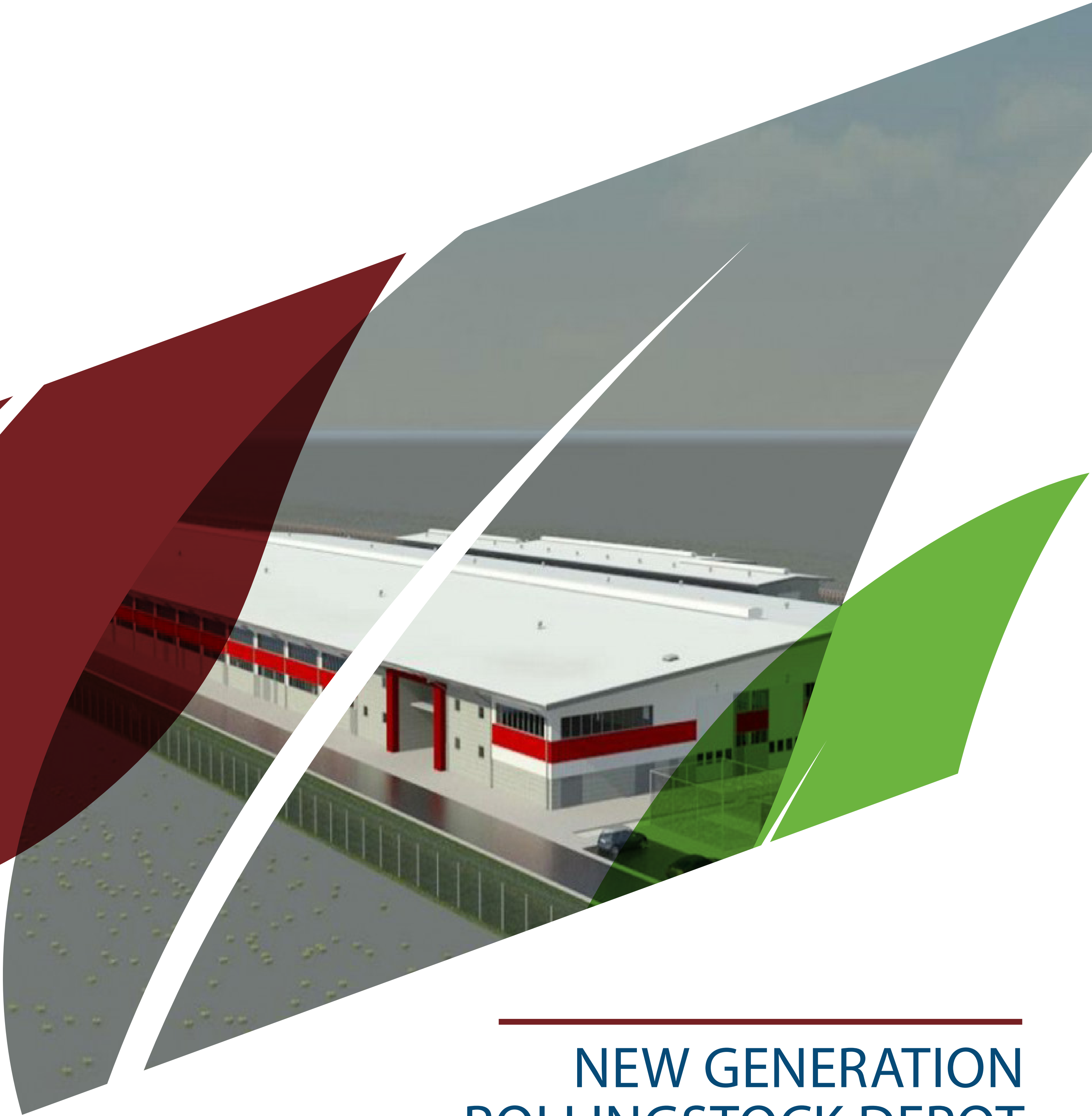

NEW GENERATION ROLLINGSTOCK DEPOT

CASE STUDY REPORT

Sustainable Built Environment National Research Centre

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EXECUTIVE SUMMARY

This report summarises the findings of a case study on Queensland's New Generation Rollingstock (NGR) Project carried out as part of SBEnrc Project 2.34 *Driving Whole-of-life Efficiencies through BIM and Procuremen*t. This case study is one of three exemplar projects studied in order to leverage academic research in defining indicators for measuring tangible and intangible benefits of Building Information Modelling (BIM) across a project's life-cycle in infrastructure and buildings.

The NGR is an AUD4.4 billion project carried out under an *Availability Payment Public-Private Partnership* (PPP) between the Queensland Government and the Bomabardier-led QTECTIC consortium comprising Bombardier Transportation, John Laing, ITOCHU Corporation and Aberdeen Infrastructure Investments. BIM has been deployed on the project from conceptual stages to drive both design and the currently ongoing construction at the Wulkuraka Project Site. This case study sourced information from a series of semi-structured interviews covering a cross-section of key stakeholders on the project.

The present research identified 25 benefits gained from implementing BIM processes and tools. Some of the most prominent benefits were those leading to improved outcomes and higher customer satisfaction such as improved communications, data and information management, and coordination. There were also a number of expected benefits for future phases such as:

- Improved decision making through the use of BIM for managing assets
- Improved models through BIM maturity
- Better utilisation of BIM for procurement on similar future projects
- New capacity to specify the content of BIM models within contracts.

There were also three benefits that were expected to have been achieved but were not realised on the NGR project. These were higher construction information quality levels, better alignment in design teams as well as project teams, and capability improvements in measuring the impact of BIM on construction safety. This report includes individual profiles describing each benefit as well as the tools and processes that enabled them. Four key BIM metrics were found to be currently in use and six more were identified as potential metrics for the future. This case study also provides insights into challenges associated with implementing BIM on a project of the size and complexity of the NGR. Procurement aspects and lessons learned for managers are also highlighted, including a list of recommendations for developing a framework to assess the benefits of BIM across the project life-cycle.

1. ABOUT THIS REPORT

This report presents findings from an investigation carried out on the *New Generation Rollingstock* (NGR) Project based in Wulkuraka at Ipswich, Queensland. It summarises the results of the analysis of a series of interviews with key project stakeholders. Each interview was conducted in accordance with the specifications of the SBEnrc Project 2.34 *Research Protocol* and *Communications Strategy*.

This report in its entirety is primarily based on interpretations of information sourced from the interview sessions and only occasionally makes references to other sources of literature to support the primary data. The points highlighted in sections 4 through to 10 were generated from verbatim accounts derived from stakeholders who, at the time of the writing, are directly involved in the implementation of the NGR project.

The report is organised as follows:

- Sections 2 and 4 provide the context for the results;
- Sections 5 through to 13 summarise the main conclusions from the analysis of interview themes;
- Section 14 contains a list of sources, external to the NGR project, which justify the main points highlighted in the body of the work;
- Section 15.1 lists the questions which prompted the conversations during the interviews. As the interviews were semi-formal, there were negligible variations in the content of the questions asked; thus, the list is provisional and reflects the key questions posed to all interviewees without exception.
- Section 15.2 provides a summary of the key software tools used on the project.

2. CASE STUDY OVERVIEW

This research covers four main questions:

(1) What *frameworks* and *benchmarks* exist nationally and internationally that could be applied to the evaluation of whole-of-life benefits gained from implementing BIM during procurement and asset management?

(2) What *KPIs* and *success criteria* must be considered in order to measure and monitor financial benefits, productivity gains, effective team integration, sustainability/resource efficiency, disaster risk preparedness, and sustainability factors throughout the life-cycle of assets?

(3) How do existing *procurement guidelines* align with the defined KPIs and success criteria?

(4) What are the *tangible* and *intangible benefits of implementing BIM* in the procurement of building and infrastructure assets for different stakeholders?

This case study aims to promote an understanding of strategies for leveraging BIM processes and tools during the early design stage on construction projects. Within a three-day period (19 March, 07 April and 09 July - 2015), seven project participants were interviewed across two broad locations; the NGR project site and interviewees' private offices. The interviewees were key project stakeholders whose roles included: Project Leadership, Project Management, Design (Architecture), Quantity Survey and Project Planning. Overall, the group represented the client, contracting and consulting stakeholder groups.

This case study aimed to provide answers to the following questions, namely:

- How does BIM-based design for project delivery differ from traditional (2D) methods?
- What do stakeholders with first-hand BIM experience consider as the benefits of BIM on their projects?
- How are those benefits realised? That is, which features or tools act as drivers?
- Are there internal project or organisational goals related to BIM benefits?
    - If so, what are they or what might they be in the future?
- What are the impacts of BIM on the procurement process (including: barriers, access to important standards and guidelines, training and skilled personnel as well as contracting, approval processes, etc.)?
- What is the best way of presenting the final SBEnrc Project 2.34 output in order to serve as a practical tool for practitioners?

The undertaking of this research is within the ambits of a confidentiality agreement with Laing O'Rourke. Consequently, this report and its findings have been anonymised and undergone review and approval by a designated representative of the New Generation Rollingstock Depot Project. The report has also been reviewed by the Project Steering Group encompassing all SBEnrc core partners and project affiliates.

3. ACKNOWLEDGEMENTS

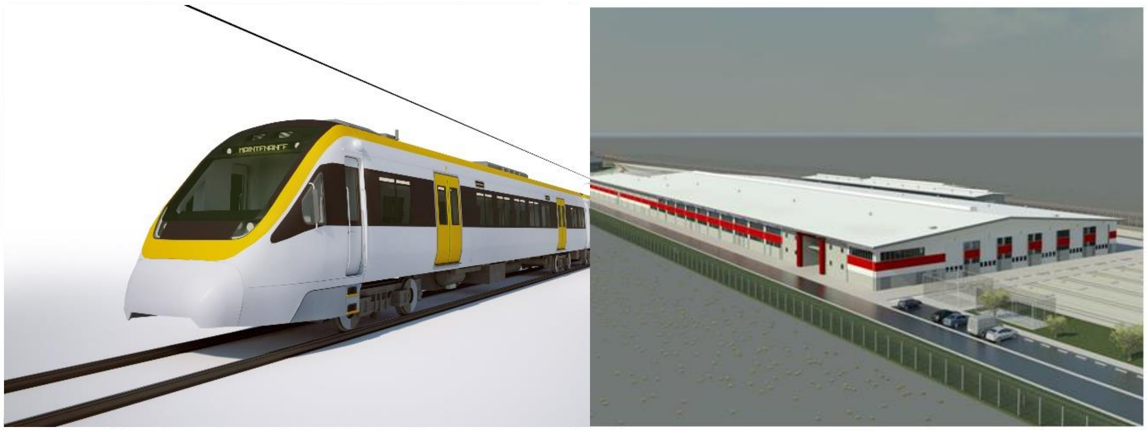
SBEnrc would like to express its gratitude to the Queensland Government and Laing O'Rourke for allowing access to their staff and documentation to carry out this research. The research team would also like to acknowledge the time donated by the interviewees who were open and cooperative at all times.

Additionally, SBEnrc would like to acknowledge the funding and support provided by SBEnrc Core Partners: Aurecon, Curtin University, Government of Western Australia, Griffith University, John Holland, New South Wales Roads and Maritime Services, Queensland Government and Swinburne University of Technology. The support from Projects Affiliates is also acknowledged.

4. ABOUT THE NEW GENERATION ROLLINGSTOCK (NGR) DEPOT PROJECT

The AUD4.4 billion project based in the South East of Queensland will serve as an upgrade of existing, albeit ageing, rail fleets and increase current fleet capacity by 30 per cent. This project was procured by the Queensland Government through an *availability payment Public Private Partnership (PPP)* strategy. It includes the design and construction of a state-of-the-art maintenance facility at Wulkuraka for exclusively servicing NGR trains over a 32-year term.

The project has a mid-2016 target date for part-commencement of service operation with full operations expected by December 2018 at what time the CityTrain passenger network will comprise NGR trains in at least one out of every two operational trains. The Bombardier NGR Consortium consists of Bombardier Transportation (principal contractor), John Laing, Itochu Corporation and Uberior. This consortium will take overall responsibility for the delivery and maintenance of the train fleet and Queensland Department of Transport & Main Road (QTMR) is leading the delivery of the project. Queensland Rail is the designated NGR fleet operator while Laing O'Rourke is the principal contractor for the construction of the Wulkuraka maintenance centre.



(a) (b)

Figure 1 New Generation Rollingstock (NGR) (a) Train Fleet and (b) Maintenance Centre (Queensland Government, 2015).

4.1. AVAILABILITY PAYMENT PUBLIC-PRIVATE PARTNERSHIP (PPP)

Availability payments and PPPs is defined by The World Bank (2012) as:

> *"a regular payment or subsidy over the lifetime of a project, usually conditional on the availability of the service or asset at a contractually specified quality". (Availability Payment)*
>
> *"A long-term contract between a private party and a government agency, for providing a public asset or service, in which the private party bears significant risk and management responsibility" (PPP)*

The combined model, known as an Availability Payment Public-Private Partnership permits private sector funding of public infrastructure project in addition to part-government funding for project delivery (Queensland Government, 2015).

The suitability of the procurement strategy to the NGR project is justified by the recommendation of the Australian Government (2008) of the procurement option as a *value for money driver*. Specific drivers for the NGR project include: better cost savings, improved risk sharing and a confidence, overall, about meeting the project schedule requirements. As a result, based on the unique contractual arrangement, payments to the consortium are tied to fulfilment of milestones.

The project is a contract undertaken by the Queensland Government in conjunction with the Qtectic consortium comprising: Bombardier Transportation, John Laing, ITOCHU Corporation and Aberdeen Infrastructure Investments – with overall procurement management by Qtectic and Bombardier (Queensland Government, 2015).

4.2. PROJECT STRUCTURE

Figure 2 illustrates the relationship between stakeholders on the NGR project and Table 1 provides a summary of their specific roles.

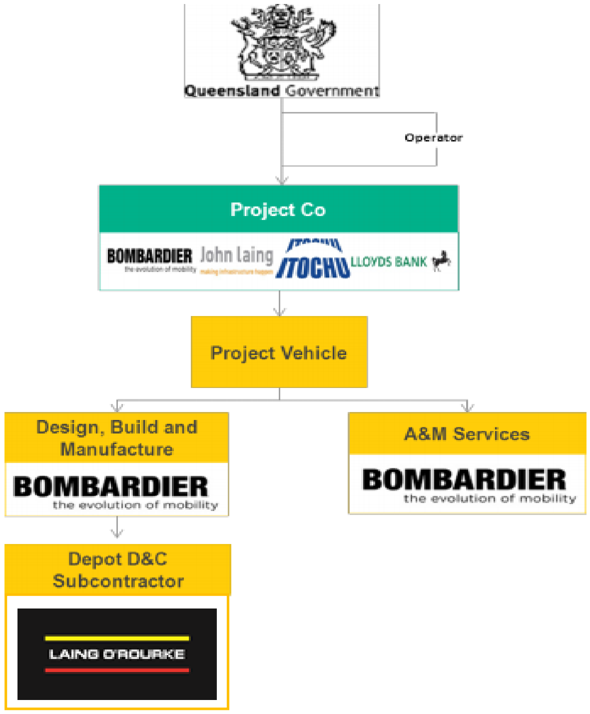


Figure 2 NGR Project Structure (Clark, 2014)

Table 1. Stakeholders and their obligations on the NGR Project coined from QTECTIC (2015) and Clark (2014)

Stakeholder	Role
Queensland Government's Department of Transport & Main Roads (TMR)	Lead Queensland Government project delivery agency
Queensland Rail	Nominated fleet operator
John Laing	Preferred Tenderer
Bombardier Transportation	Principal contractor to Qtectic for the design, construction, delivery model consisting of linked but distinct component models, drawings derived from the models, texts, and other data sources that do not lose their identity or integrity by being so linked, so that a change to one component model in a federated model does not create a change in another component model in that federated model and maintenance of the NGR fleet
Laing O'Rourke	Principal contractor for Wulkuraka Maintenance Centre construction
ITOCHU	25% equity shareholder (ITOCHU Group, 2014)

4.3. SOFTWARE MANAGEMENT ON THE NGR PROJECT

A range of BIM software packages and other supporting tools, outlined in section 15.2, were deployed on the project to support the creation, dissemination and update of accurate project information.

An important attribute of the deployed software packages is their use for specialist work. For instance, one software package may be deployed to create a particular element or fixture and completely different software may be required to create a nearby element with which the component in question interfaces. The requirement for information exchange between software packages without loss of data/information, known as interoperability, is a challenging aspect of BIM which has been discussed extensively in research (CRC for construction innovation, 2009; Grilo, Zutshi, & Jardim-Goncalves, 2011; Pauwels, De Meyer, & Van Campenhout, 2011). Some of these challenges were highlighted by some respondents and deserve further investigation.

A common challenge related to software interoperability was information exchange between a variety of software packages and the federated model[1]. This was especially the case during the design and pre-construction stages. Additionally, some of these software packages did not support direct links with external software. While the federated model served as a repository for coordinating all project information, considerable effort was required to ensure that all relevant aspects of the project were either fully modelled or represented within the model in some way or form. At the time of writing, such project efforts included:

- Mandating project stakeholders to exchange digital information during project design and construction.
- Stipulations for the production of a minimum amount of 3D information for the model.
- Creation of new lessons learned on the interaction between dissimilar software interfaces.
- Development of digital information management competencies.

Notwithstanding the temporary shortcomings however, respondents unanimously agreed that the value derived and subsequent ease that accrued from working based on the central model, for instance in stakeholder communication and issue escalation, outstripped their initial concerns.

5. BIM BENEFITS

The benefits of BIM deployment on the NGR project, as suggested by the interviewees are, summarised in Tables 2, 3 and 4. These tables outline benefits identified by the interviewees and later classified according to the Benefits Dictionary developed as part of the BIM Value Realisation Framework in Project 2.34 (descriptions available through BIMValue online tool). Table 2 contains realised benefits; those which

[1]A federated model is an object repository comprising linked, independent model elements and graphics that are extracted from other graphical/textual data which themselves do not undergo any changes upon contact with other elements (Porwal & Hewage, 2013).

interviewees have personally realised so far in the course of their involvement with the NGR project. Table 3 includes expected benefits; those benefits yet unrealised (at the time of writing), but which are expected in the near future based on planned BIM uses. Table 4 includes unrealized benefits; benefits that the interviewees had hoped to realise based on their knowledge or experiences from other projects but were not achieved due to project-specific constraints. Short profiles of these benefits can be found in section 13.1 describing how they were perceived by the interviewees. The contents are listed in alphabetical order.

In all, 88 benefits derived from the use of BIM were suggested during the interview sessions. This number was revised down to 58 after eliminating repetitions, with 16 of the entries suggested more than once across the interview sessions; where this is the case, the number of times the entry was mentioned is placed in (parentheses) beside the entry in question. Consistent with the specifications of the BIM benefits dictionary, Table 3 maps the benefits originally identified on the NGR project to the 36 benefits specified in the benefits dictionary. The benefits not covered within the content of the dictionary are listed alphabetically under Table 3 as other benefits.

Table 2. Summary of realised benefits (sorted alphabetically) based on the benefits dictionary

- Asset management labour utilisation savings
- Better change management
- Better cost accounting
- Better data/information capturing
- Better environmental performance
- Better programming/scheduling
- Better scenario and alternatives analysis
- Better space management
- Better use of supply chain knowledge
- Competitive advantage gain
- Faster regulation and requirement compliance
- Fewer errors
- Higher customer satisfaction
- Higher process automation
- Improved communication
- Improved coordination
- Improved data and information management
- Improved documentation quality and processes
- Improved efficiency
- Improved output quality
- Improved productivity
- Improved safety
- Optimisation of construction sequence
- Reduced execution and lead times
- Reduced risk

Table 3. Summary of expected benefits (sorted alphabetically)

- Better utilisation of BIM for procurement on similar future projects
- Enhanced capacity to specify the content of BIM models within contracts
- Improved decision making through the use of BIM for managing assets
- Improved models through BIM maturity

Table 4. Summary of unrealised benefits (sorted alphabetically)

- Better alignment in design teams as well as project teams
- Capability improvements in measuring the impact of BIM on construction safety
- Higher construction information quality levels.

6. BIM BENEFITS ENABLERS

Table 5 provides a list of the tools, actions and processes identified by interviewees as being associated with or which were required to achieve specific BIM benefits. All of the listed enablers are in current use on the NGR project and reflect the opinions of the project stakeholders about important factors in the realisation of project-specific BIM benefits. Short profiles of these enablers may be found in section 13.4, including examples of how they were realised in relation to specific benefits.

Table 5. Summary of benefit enablers (sorted alphabetically)

- 3D control and planning
- Asset knowledge management
- Automated clash detection
- Common data environments
- Constructability analysis
- Cost estimation (quantity take-off)
- Data-rich, geometrically accurate model components
- Design authoring (3D visualisation)
- Design reviews
- Early and effective stakeholder engagement
- Engineering analysis
- Front-end planning
- GIS-BIM
- Integrated model and program management systems
- Online collaboration and project management
- Phase planning (4D modelling)
- Virtual walk-through and animations

7. BIM BENEFITS METRICS

The interviewees felt that there were no readily available quantitative BIM metrics due to factors such as information sensitivity and the complexity of the project's supply chain. For instance, it was considered near impossible to objectively determine how much time savings a project had realised due to implementing BIM as opposed to using traditional methods. There were no experimental set-ups or control measures that ran in parallel to the NGR project. Nevertheless, interviewees felt that it was possible to use qualitative criteria as metrics for BIM benefits in the first instance. It was generally agreed however that a quantitative measure on the benefits of BIM would serve as a valid means of stimulating a more vigorous adoption of BIM tools and methodologies across industry.

7.1. METRICS USED ON THE NGR PROJECT

Notwithstanding some of the highlighted challenges with quantitative approaches to measuring BIM benefits, a participant argued that a useful approach to determining metrics for benefit measurement is through value measurement. It was proposed that BIM stakeholders can reflect on *how much time* it would typically take to accomplish a BIM-based task versus undertaking the same task based on traditional approaches. Based on this estimation, they can then determine the dollar value of the difference. However, this method assumes that the traditional way of implementing such an activity has been well documented and catalogued in some database or learning system.

In addition to comparisons based on time measurement, another metric suggested was measuring the differences in the amount of defects/non-conformances in delivering a specific product of the project based on traditional and BIM-enabled approaches. Likewise, this presupposes that such measures were already in place while delivering projects via traditional approaches and that the measurements in both scenarios are accomplished independent of all other external factors.

Some stakeholders were of the opinion that a reasonable way to measure BIM benefits is through clash detection, and tracking clashes that arise in the course of building design and construction. In the opinion of an interviewee, it is unrealistic to expect the entire project to freeze at a specific point in time. Moreover, it was considered that the challenges with clash detection and tracking are exponentially more complex for a fast-tracked[2] project than one procured under a different, less aggressive form of design and construction. For instance, a single requirement from clients for variations to previous component design alone could result in significant clashes recorded on the model.

Rather than deal with the intricacies of measuring the benefits of BIM, most of the project stakeholders focused on capacity building through lessons learned databases to provide guidance on similar future projects. For instance, an interviewee disclosed that by focusing on data validation, they have progressively developed capabilities that will serve as standards against which future projects in his organisation will be benchmarked.

Summaries of current and potential approaches to BIM benefit measurement are listed in Table 6 and Table 7 respectively.

Table 6. Current BIM Metrics (sorted alphabetically)

- Getting zero clashes
- Programme and work sequence
- Reduced number of issues
- Scope measurement using 3D, 4D and 5D

[2] Fast tracking entails the overlapping of procedures and processes in the design and construction phases within a project environment; tasks which are typically done in silos could occur simultaneously.

Table 7. Potential BIM Metrics (sorted alphabetically)

• Clients' satisfaction • Collaboration with Work Package Manager • Confidence in and certainty about model content	• Software compatibility • Stakeholders' Feedback • The quality of benefits to clients and the supply chain

8. BIM, PROCUREMENT AND ASSET MANAGEMENT

This section summarises the topics highlighted by interviewees in relation to BIM during design and procurement. Although some comments were specific to the NGR case study, the lessons learned and comments are based on long-standing professional experience of interviewees across a number of BIM-enabled projects. They are intended as 'word of advice' for other managers.

- <u>Work Scoping:</u> The model was used at early planning stages for determining and managing the project scope providing opportunities for improvement. On the NGR project, data derived from the procurement information is used to create work codes which are then aligned with planning codes.
- <u>Turnkey Solution:</u> As a repository of integrated project information from conceptual stages, through procurement to implementation, efficiency gains on the project have been attributable to the use of BIM. At that stage of the project, it is expected that the short term procurement strategies would result in long term management gains even during facilities management in the long term.
- <u>Contract, Designs and Payments on a PPP:</u> As the project was procured through an Availability Payment Public-Private Partnership, there are different payment mechanisms at play on the NGR project. BIM deployment implies that there is relative ease in documenting progress payments. By taking advantage of the various benefits of model-based project delivery there is an increased potential for meeting design obligations early enough so that full payments are made based on timely task achievements.
- <u>Contract forms:</u> An interviewee highlighted that PPPs are similar to negotiated contracts which were seen as producing value and being effective, albeit dated. An integrated team approach to project procurement allows efforts of all parties involved to converge towards a common goal. In this manner, it was indicated that BIM is well suited to PPPs. It was also argued that BIM cannot be constrained to any one contract or procurement method, rather it can be adapted to suit the contract methodology of projects. The strengths of digital modelling were however seen to probably be best suited to design & construct contracts. In this case project stakeholders are responsible for ensuring close ties between the design and construction teams.
- <u>Industry/Government Mandate:</u> In the course of the interview, it was revealed that the enormity of the observed and recorded BIM benefits on the NGR project (at the time of this report) in addition to other examples of successfully executed BIM-based projects should serve as evidence for pushing for an industry-wide BIM mandate. This aligns with the current aims of the UK Government to ensure that all government-procured projects from 2016 are level 2 BIM-compliant (integration). Furthermore, a useful benefit of BIM-based procurement is derived from accumulated lessons learnt on each project.
- <u>Client Roll:</u> In the opinion of some project participants, early benefits can be gained if BIM deployment is an explicit client requirement during the conceptual stages of projects. It is believed

that, subsequently, such specifications will drive the delivery of tangible project value through the integration of BIM tools and processes throughout facility lifecycles.

Although the use of BIM on the NGR project was not as a result of a mandate, some interviewed stakeholders were of the opinion that BIM benefits on other projects throughout Australia can be better designed and implemented if the Government drives a mandate for BIM-based project delivery. Their reasoning stems from related examples around the world where BIM has received the support of Government which in turn has resulted in well documented productivity gains in product delivery (BIM Industry Working Group, 2011).

Similar to Government institutions, individual and corporate clients have required BIM deployment on projects across the built environment. In comparison to projects delivered via a traditional platform, such requests from stakeholders will inform the procurement of sustained BIM benefits.

9. PROJECT CHALLENGES

This section presents an overview of some challenges encountered so far on the NGR project, most of which were linked to the use of modelling tools, model requirements and actions by some stakeholders. For instance, team members not using tools appropriately experienced limited knock-on effects on other aspects of the project.

- Software limitations and Compatibility Issues: In the context of this report, software compatibility is concerned with whether or not a piece of software is fit for purpose. On the NGR project, there were concerns about the capacity of the primary software tool (Revit) to model in-ground services; elements and design components below ground level. It was argued that this challenge is not unique to the project; rather it is a result of current software limitations.

  Furthermore, as the NGR is primarily a Civil Infrastructure Project, there were few challenges with modelling the design elements on the project. In the opinion of an interviewee, for instance, certain pieces of software are better suited to these types of projects than are others. A case in point was the inability to accurately model certain aspects of the construction work like trenches as this would result in clash reports stemming from the tool's misinterpretation of a trench as a gap. In turn, an awareness of these challenges has informed the investment of extra effort and resources to ensure that on-site issues arising from design-decisions are proactively addressed.

- Software Interoperability[3] and non-precedent projects: While compatibility issues arise as a result of the inability of a specific piece of software to efficiently execute a designated function, challenges with interoperability are a consequence of the incapacity for information exchange between two or more software tools. In other words, if information from one software tool cannot be accurately mapped to another, it is usually an indication of a lack of data interoperability. An example of this from the NGR project was the significant concern about interoperability between 12D and Autodesk's Revit tools. The impact of the problem affected documentation of the areas external to the building model such as fences and the project site.

[3] Interoperability is the term that describes the ability of software tools to exchange information without loss of data/information.

Similarly, Microstation (a 3D software tool by Bentley) was used primarily for modelling rail elements while Revit was used for modelling MEP (mechanical, electrical and plumbing) components and 12D (by 12D solutions) for roads and earthworks. As a result, there were initial interfacing issues, for instance between 12D and Navisworks. The complex problem of information exchange between these software tools required significant effort in resolving, not to mention the exchange of information between 3D and non-3D software systems.

It was argued, however, that while the technological platform deployed for use on the project was tried and tested, there were no precedent projects in Australia which had successfully combined the deployment of the various software tools for BIM-based project design and delivery. Consequently some project team members suggested that a useful approach to dealing with the complex use of an array of non-interoperable software tools is to determine the suitability of software tools to the project tasks for which they are required. Thereafter, concerted effort can be invested in getting the software platforms to communicate and accurately exchange information.

- Uniformity of data requirements: In meeting their deliverables, some consultants on the NGR project had to utilise the software tools considered best suited to the execution of their functions. However, as consultants' functions differed, so too did their software tools with the effect that the datasets presented for use in the central model had different levels of details and were formatted differently. One consultant recalled that in order to address the challenge, he developed data for use in the model in two formats; one for the delivery of his primary function and the other for meeting the model requirements.
- Stakeholders' Capabilities: The ease of setup and design on the NGR project was considered a function of the expertise of contractors and consultants as well as their previous experiences on similar projects. Architects were considered the most experienced in digital modelling and the use of a range of software tools leaving a gap between their knowledge base and those of Engineers and other professionals on the project team.

  A case in point was the on-boarding of a project team member who, although a professional in his field, underwent hands-on BIM training in order to (i) generate accurate data from his software system for subsequent deployment to the federated model, and (ii) to get up to speed with the other members on the project team. The ability to engage with Architects, designers and engineers who were truly BIM-literate and competent, was considered essential to the progress of the project.

  However, there were few drawbacks associated with incompatibilities in the experiences and capabilities of contractors and consultants that were related to the nature of the project being a rail project rather than a typical building project.

- Initial Effort Required: Closely associated with the capabilities of consultants was the setup time required during early design. It is expected that it will take consultants with significantly more experience less time to be productive than it would the less experienced project stakeholders. In this light, some participants felt strongly that setting up was both labour and resource intensive. Sufficient consultant experience during the design phase in order to understand what needs to be complete before the commencement of construction is therefore essential.
- Difficulty in usage and updating of tools: Meeting the requirements of the federated model created information constraints which were considered challenging by some consultants, in particular those who did not use the federated model as a primary tool.

Also, as different consultants joined the project at different times, considerable effort went into updating the central model with all the information required for certain consultants to commence working on specific aspects of the project.

- Insufficient Awareness of design and project implications: When reflecting on stakeholder engagement and management, an interviewee suggested that the project team's efficiency could have significantly benefited much more from aligning the model intent with the work methods and priorities of the project team and client's goals from very early on at the conceptual stage of the NGR project.
- Reverting to traditional work-processes: The effect of new ways of working and steep learning curves on the adoption of BIM-based project delivery was noticeable at the onset of the project. In a few cases where there were issues with interfacing with the software, some members of the project team were observed to have reverted back to the use of traditional tools and methodologies, especially when under the pressure of task delivery. A slightly similar manifestation of this project constraint is in the inadequate or total absence of any form of reference to the content of the model in executing particular tasks; this has a ripple effect on overall workflow for every activity linked to the tasks in question.
- Poor documentation: It is believed that the design consultant's general maturity level in BIM at the start of the project held up documentation and modelling works. As a result, overall responsibility for leading the project's design was designated to the Architectural team based on expectations that their knowledge of documentation relevant to the project's objectives and the delivery team's needs would be brought to bear on the project process.
- Inadequate Data Management: There were noticeable issues with timely data gathering, interrogation and interpretation. In one case, an interviewee felt the data management process was a bit slower than was expected, mainly due to the sometimes restrictive and recurrent nature of clash detection.

  Similarly, where the level of data derived from the model was too robust for use in other pieces of software, data considered unnecessary was stripped off from the model element. The challenge was that the stripped data was never fed back into the system after manipulation by the receiving software. In this process, data was extracted in specific downstream-friendly formats through issuing a set of guidelines to the consultants, specifying the precise data requirements of other users. Even after the rigorous process of ensuring conformity to the requirements of a receiving software platform, the extracted data further had to be coordinated for use with other model elements prior to re-uploading the data to the federated model. In other words, preserving the integrity of BIM data constituted a unique set of challenges.

- Differing Metric Systems: As several software packages were in use on the NGR project, the use of different systems of measurements was unavoidable. In one instance, this disparity implied the units of measure on a particular piece of software had to be recalibrated to align with another software tool in order to ensure consistency in the measurements of elements.
- Ambiguity in definition of KPIs: The NGR project had a dedicated team that provided assurance to the State to the end that the delivered product was fit-for-purpose and in accordance to contract specifications. Notwithstanding, there were no explicit definitions of Key Performance Indicators (KPIs) on the project. Understandably, the sense of ambiguity with respect to KPIs stems from the novelty of the NGR project. Broadly speaking, the high performance levels recorded on the project were as a result of project team members' commitment to excellence and to the delivery of value to the project and the discovery of new learning points for use on future projects.

- Supply chain management: Notwithstanding the reported success in leveraging the model to integrate implementation efforts, one interviewee in particular expressed that much more integration could have been realised across the supply chain if more supply chain partners were involved earlier on in the project.
- Service Procurement: Although stakeholders can relatively easily be made aware of the benefits of BIM deployment on projects, the more significant challenge is figuring out how to effectively procure associated services. This difficulty stems from the disparity in consultants' native/proprietary capability to link BIM to other project management software for the delivery of a single project. The question remains; *how can clients procure these diverse services, how can they be convinced to invest money upfront in the planning and delivery of other projects, and how can value-for-money on future BIM-procured projects be demonstrated?*

10. LESSONS LEARNED FOR MANAGERS

In addition to some of the highlighted benefits in previous sections, the following are additional learning points gleaned from the interview sessions. These have been summarised to contain the key points on the project that could potentially be useful to managers.

- In complex civil projects involving above-ground and in-ground services, it is worth deciding early what tools to use in modelling the services, and the time and resource capabilities required for achieving the task. Essentially the project will benefit from adopting the technology to the process.
- Keeping all stakeholders informed on the progress of the project is important. A consultant's company on the NGR project for instance featured the NGR project on its quarterly newsletter, thus keeping interest alive and placing the project within the context of the organisation's strategic goals.
- Some key benefit of digital modelling is the ability to visualise (3D) the product of the project, as well as accurately determine activity and build sequencing (4D). On the NGR project, these have led to substantial time savings by way of enhanced collaboration and communication across the project teams.
- While challenges are inevitable during construction projects, many problems can be resolved very early during design by taking advantage of the digital model when there are little to no cost implications for making adjustments to the original design.
- The federated Building Information Model provides a controlled environment for information exchange, coordination of drawings and project scheduling because all project participants work off a single model.
- Working based on the specifications of a central model eases the learning curve and improves overall comprehension of the coordination processes involved in project delivery.
- There is still some value in referring to 2D drawings as these are not as easily compromised as 3D models. However, the benefits of working based on BIM processes makes it increasingly difficult to work based on traditional arrangements.
- Increasingly, clients are driving the use of BIM on projects as they value the ability to drive the outcomes of the project based on their unique requirements.
- Relative ease of performing previously rigorous construction activities has been achieved by working off the model. For instance, it is possible to accurately model massive civil structures, and break them up into a system of precast elements that can be placed onsite without any problems.

Effectively, using the 3D model ensures such high risk tasks are executed safely based on the writing of a safe work method statement based on model simulations.

- The value that BIM delivers is much more than the benefits accruable from clash detection alone.
- There is inherent value in engaging contractors and experienced stakeholders from the supply chain very early in the project. Their experience can make all the difference as most times, they can inform the project team of the implications of early design decisions at later stages of the project and how to address those challenges if and when they occur.
- By developing different ranges of programmes for the project, activity sequencing and schedules can be adequately managed in conjunction with visualising the project in the long and short term. They are also useful in data validation in terms of comparing the planned work to the actual implementation of the project work.
- On the same project, BIM may not necessarily be the primary tool for all stakeholders. However, in all instances, it can be used as a support tool to software and processes alike, especially in the communication management and information exchange.
- The process of integration requires strong buy-in from the supply chain to make digital modelling as effective as possible, especially through the early involvement of mechanical, electrical, and plumbing contractors and suppliers, steel work contractors and even the earth works contractor.
- Ensuring tie-in between BIM models and project conformance by linking the model to the project plan, such that changes to the model are synchronised to program changes.
- It is essential that BIM models are detailed very early on and that these details are linked to geometric model information.
- In terms of the productivity gains consequent upon reduced clashes within the digital model, stakeholders' expectations are increasingly being met – up to 60% in one recorded case. This figure is bound to increase considerably with a bit more effort from the designers in terms of developing, updating and maintaining the model.
- Ensuring that the model elements are detailed at appropriate levels can drive further time savings and reduction in effort downstream during building design and construction and afterwards, during facilities management.
- It is possible to develop proprietary protocols capable of linking project management tools (such as Primavera P6) to the model and coordinating the entire process with project schedules (4D).
- Effective management of the project can be the result of using suitable contracting forms and procurement methods; Design and Construct (D&C) and Public-Private Partnerships (PPPs) respectively in the case of the NGR project.
- Successful BIM-based project delivery is often the result of 80% of good human resource management and 20% of technological support. The determination of members of the project team to execute a successful project alone can produce outstanding results.
- Advances in BIM software functionalities will lead to reduced challenges in deploying BIM approaches for building design and construction. Yet, the aspects of project management with BIM that should remain unchanged are:
    - The principles of value-adding design and construction.
    - Continuous learning.
    - Adapting to the changing face of an AEC industry; an industry that is leveraging technology in addressing challenges in building design and construction.
- The industry will stand to gain from up-skilling existing and new manpower with BIM capability and knowledge and coordinating construction work by ensuring conformance to standards.
- It is important that in adopting BIM for project delivery, a premium is placed on conformance to the project brief and that the overarching focus is on achieving the end product.

- Continued exposure to BIM-enabled projects will equip industry with the wherewithal to tackle the unique, albeit surmountable, challenges of a BIM paradigm. Consequently, project management efficiency is very likely to increase over time.
- With increased use of BIM, project documentation is bound to be better, thereby reducing many of the drawbacks of traditional methods of documentation; lengthy delays that typically result in time and cost overruns for instance.
- As the introduction of a new system such as BIM cannot pay for itself, the cost of BIM education can be shared across the AEC including research (universities) and practice (industry).
- Greater efficiency gains than have been previously recorded can be attained by ensuring that the tools used on the project have the capacity for supporting interoperable information exchange.
- On multidisciplinary projects, it may be useful to have a dedicated project team member who will function primarily in the role of a BIM super-user and who specialises in troubleshooting and problem-solving. Such a resource will be core to easier, cross-disciplinary communication and model collaboration.
- Early involvement of project team members (as soon as their expertise is required) in processes connected to their roles will enhance data management throughout the project lifecycle. That way, planning for the project deliverables will take input from the relevant professionals who will be responsible for their outputs. An appropriate time to engage these stakeholders would be prior to onsite mobilisation.
- The Return on Investment (ROI) implication of the PPP procurement strategy for clients is that although there is an indirect project payment, there are some accruable benefits as the payment is not upfront.
- As most aspects of project information are captured digitally, the time spent in creating such information from scratch in traditional settings is drastically minimised and reinvested into the achievement of more productive, project-specific tasks.

11. PROJECT OUTPUT RECOMMENDATIONS

This section is an overview of discussions and suggestions gathered from the interviews regarding user-preferences for a framework that encapsulates BIM benefits specific to particular stages of the building lifecycle.

While a particular stakeholder mentioned the possibility of converting the number of clashes identified and resolved in monetary terms, he opined that the ultimate focus of projects should be the complete satisfaction of project clients; by finishing in time and on (or below) the budget. This way, the value of utilising a BIM-oriented approach would be better appreciated. However, he noted that there was no readily identifiable way of representing the identified benefits of BIM throughout the building life-cycle. The same sentiment was expressed by other stakeholders.

Nevertheless, a few suggestions regarding a format for presenting BIM benefits were obtained, namely:

- A benefits matrix: for instance a two by two (2X2) matrix with a hierarchy that allows stakeholders in the AEC to conduct self-assessment exercises in order to determine how they rank in relation to others within the industry.
- A visually interactive tool: to enable BIM users, especially engineers, to determine the extent to which their projects have attained the ideal in terms of BIM maturity.

- Localisation of international strategies: since systems in use in most parts of the world are borrowed from elsewhere. Therefore, a tool that shows users how international frameworks that served as the basis for benefits realisation on other projects can be tailored to local requirements.
- Case-study based comparative analysis: by chunking similar projects on which BIM adoption had similar impacts versus another group where there BIM deployment is absent on the basis of the benefits to the end users; clients, contractors, consultants. In this strategy, the use of metrics like, time, cost, quality and safety, was also recommended.
- Reports: which elaborate on the benefits that can be derived from deploying BIM for building design, construction and management and recommendations on strategies for training and networking with the right resources to facilitate positive outcomes after the training sessions. It would also be useful to scope the industry to identify industry leaders in BIM deployment and successfully BIM-based projects.

As to the preferred content of the benefits schema, one respondent suggested that a tool will be appropriate which takes cognisance of parameters such as economic gains, quantification of criteria perceived unmeasurable, and increasing the digitisation of building information.

12. PROFILES

This section provides profiles for benefits and enablers mentioned in Sections 5 and 6 based on case study data.

12.1. BENEFITS

The following subsections elaborate on the benefits outlined in section 5. These are based on all the data available from the case study. Each benefit is summarily discussed and where possible, examples are provided.

12.1.1. ASSET MANAGEMENT LABOUR UTILISATION SAVINGS

Expected during asset management - Although the NGR project is ongoing, there are plans to leverage the complete model for facilities management. The long-term implication, according to Facilities Net (2014), is that BIM can be beneficial after project handover through links to the facility's maintenance management system.

12.1.2. BETTER CHANGE MANAGEMENT

Design and construction - Version updates and clash detection are highly relevant BIM functions that lend significant value to project change management. Given that the stakeholders work based on a single federated model, necessary changes to the digital and non-digital contents of models are quite easily implemented tracked, and managed.

Construction - Since on-site work can be visualised from within building models, it was observed through a range of trials that the overall effort required for effective activity implementation can been significantly reduced. For example, iPads were trialled with the onsite work crews to provide access to rich and relevant information and documentation in the field. This promoted increased efficiency as crews had information available to them immediately to support making decisions. Network connected iPads removed the need to carry bulky paperwork or return to the site office to source the required project information and documentation.

12.1.3. BETTER COST ACCOUNTING

Design and construction - By plugging in the elemental quantities generated through automated quantity take-off to linked costing software, efficient budget management has been realised on the project.

12.1.4. BETTER DATA/INFORMATION CAPTURING

Design - A majority of work at the Wulkuraka project site is first visualised and discussed. It has been suggested that the effectiveness with which several rigorous tasks have been successfully performed is a testament to the solid knowledge base garnered from engaging with the model prior to actual construction.

12.1.5. BETTER ENVIRONMENTAL PERFORMANCE

Design - In line with its sustainability objectives, the NGR project has generated far less paper-waste than expected from a project of comparable complexity and magnitude.

Expected during asset management - Although the NGR project is ongoing, there are plans to leverage the complete model for facilities management. The long-term implication, according to Facilities Net (2014), is that BIM can be beneficial after project handover through building analysis, especially in relation to sustainability and LEED certifications.

12.1.6. BETTER PROGRAMMING/SCHEDULING

Design and construction - The robustness of the digital environment that BIM provides has been exploited in delivering the NGR project through a fast-track process. A building model can be used at any point during the building lifecycle, and this lends itself to the necessity of overlapping design and construction on a fast-tracked project. So far, there have only been minimal disruptions to the construction process due in part to the robustness of the design process and to the level of effort invested to ensure smooth transitions across design and construction.

Construction - In addition to sequencing the build process using BIM tools, time can also be modelled and simulated using 4D BIM tools such as Navisworks. This step is important because BIM environments give clients and stakeholders a visual appreciation of how the project intent will evolve over time. In turn, informed decisions can be taken on the project schedule and their impact also simulated and even compared to earlier versions of the schedule.

12.1.7. BETTER SCENARIO AND ALTERNATIVES ANALYSIS

Design and construction - By using BIM platforms, the entire project build can be simulated through a range of different techniques, including: fly-throughs, walk-throughs, activity sequencing, etc.

12.1.8. BETTER SPACE MANAGEMENT

Expected during asset management - Although the NGR project is ongoing, there are plans to leverage the complete model for facilities management. The long-term implication, according to Facilities Net (2014), is that BIM can be beneficial after project handover through visually supporting more effective use of space

12.1.9. BETTER USE OF SUPPLY CHAIN KNOWLEDGE

Design - BIM furnishes all user groups with the ability to engage in meaningful discussions about the design implications of clients' decisions during briefing sessions. The implication is a noticeable heightening of the client's attention to project critical actions and the prioritising of such issues. On occasion, taking advantage of the highly visual aspects of BIM tools, clients have given clear, concise feedback at highly detailed levels; this is near impossible in traditional settings except where the client is well experienced in the workings of the built environment.

As BIM requires the inputs of stakeholders, many project team members who are typically recruited at much later stages of project implementation are recruited early enough to make inputs to the process such that their future work will benefit from those early contributions.

Within BIM projects, designers are also integrally more involved in the project, even at the post-design stage as they possess the expertise that can inform important decision making from the conceptual to construction stages with long term implications for facilities management.

12.1.10. COMPETITIVE ADVANTAGE GAIN

Design and construction - Stimulating interests for BIM use in future projects.

12.1.11. FASTER REGULATION AND REQUIREMENT COMPLIANCE

Design and construction - A payment certificate is a verified document evidencing work completion and payment approval. Within BIM tools, this process gains from the use of BIM as a tool for speedy validation, hence prompt payment.

12.1.12. FEWER ERRORS

Design – The overarching aim of deploying BIM on the NGR project is 'getting it right the first time'. This philosophy implies that the considerable effort that goes into the design pays off during on-site construction on the basis that all risk factors associated with project activities have been identified and designated to risk owners to increase the probability of success in carrying out the work.

The parametric nature of BIM tools implies that changes to any element or parameter within a model could potentially result in a clash between elements, for instance between a structural column and an air vent. In the 2D world, it would take considerable effort to identify such clashes. Often, such clashes are identified too late in the project where there are higher cost implications for even minor changes. BIM tools and methods enable project teams to automatically view clashes within the model and to take steps for the elimination of the occurrences early on during the design stage where there are little to no cost implications of change.

12.1.13. HIGHER CUSTOMER SATISFACTION

Design - On the NGR project, the highly visual impact of the digital model has eased interaction with clients. Some members of the client's team have been so impressed that they have indicated interest in using BIM for their future projects.

The model has been used for validation. In this process, the output of the model is compared to the original specifications of the clients. Some inconsistencies were easily identified visually or through other functionalities in the BIM software and promptly rectified. The outcome of this iterative process is sustained goodwill and increased client satisfaction.

BIM has provided a common ground for client-stakeholder collaboration. Specifically, members of the client's team have verbally expressed satisfaction with the level at which BIM has been exploited on the project and the ease with which their concerns are addressed.

12.1.14. HIGHER PROCESS AUTOMATION

Design and construction - A BIM approach to project delivery encourages digitising design and construction information. In turn, the digital information opens up a series of accurate automatic options, including: clash detection, quantity take off, project documentation, change management, etc. Many of these tasks, under traditional settings, are highly error-prone and require considerable effort.

Expected during asset management - Although the NGR project is ongoing, there are plans to leverage the complete model for facilities management. The long-term implication, according to Facilities Net (2014), is that BIM can be beneficial after project handover through interaction with and supplementing of other building automation systems.

12.1.15. IMPROVED COMMUNICATIONS

Design - The building model has served as a reference point for managers on the NGR project to clarify the requirements of the project plan and the subsequent implementation of those plans on site. Usually, such clarifications are made during team meetings and during feedback sessions with members of the client's team.

BIM has furnished the stakeholders on the NGR project a digital common ground that continues to be heavily exploited especially during project team meetings and client briefing sessions. As discussed earlier, the use of BIM on the NGR project has engendered high levels of client satisfaction. Moreover, as the project plan is tied to the model, BIM has been utilised for managing client's expectations, especially since members of the client's team are very easily able to visually engage with the model design.

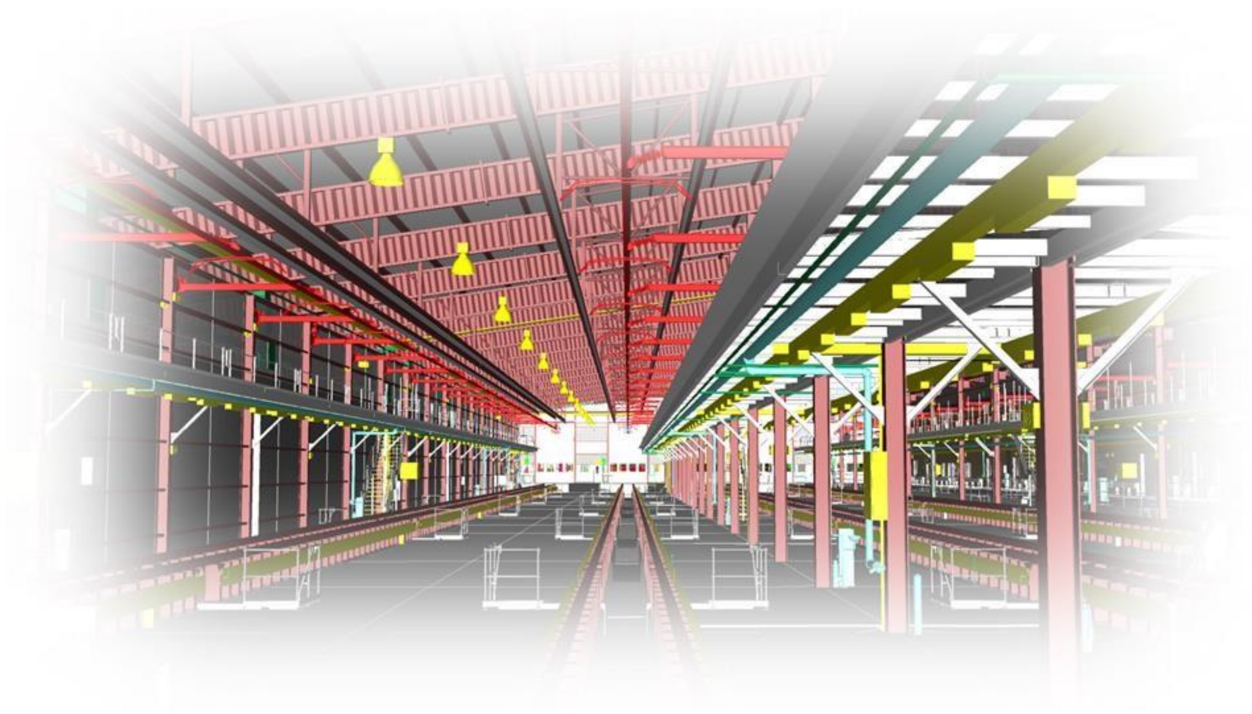


Figure 3 Model view of internal structure of the depot design

Through simulation of BIM models, architects and designers can very quickly understand the project-wide impact of their ideas. As such, they can adjust those ideas until they are satisfied that the overarching integrity of the model will not be compromised. BIM platforms also force users to undertake a clearer visualisation of the end product and helps reduce the level of ambiguities characteristic of many non-modelled plans. Members of the project team and supply chain, by continuous reference to the model, develop a clearer understanding of their deliverables and, more importantly, gain an appreciation of the impact of their portion of the project in the larger project context.

Design and construction - The BIM model has been heavily relied on during project meetings. Project team members gain a visual appreciation for their task requirements and, on that basis, are able to engage in productive, focused dialogue sessions with their supervisors, seeking clarification where necessary.

As BIM platforms are highly visual (Figure 3), clients are able to get a clearer idea of how their specifications have been interpreted by the design team. During such meetings with the clients, further clarifications on any ambiguities can be obtained. This contrasts to traditional methods of design and construction where it was not uncommon for clients to have an entirely different project vision than architects and other members of the design team.

Project participants said that an undeniable benefit of BIM is its use in determining the minimum amount of effort required in implementing a task. As there are no risks of inconsistency in the specification across the various drawings as could be the case in traditional settings, quality expectations on the NGR project have been satisfactorily met.

The early involvement of the contractor on the project has ensured transparency and ease of communication with other project stakeholders, especially as BIM is used as an effective communication tool for ensuring that clients and project team members are up to speed with developments on the model and overarching project as they occur.

12.1.16. IMPROVED COORDINATION

Design - The federated model in use on the NGR project was developed from very early on in the project with the effect that exchange of design information between project team members has been appropriately documented and coordinated. Figure 4 showcases model views used for coordination purposes.

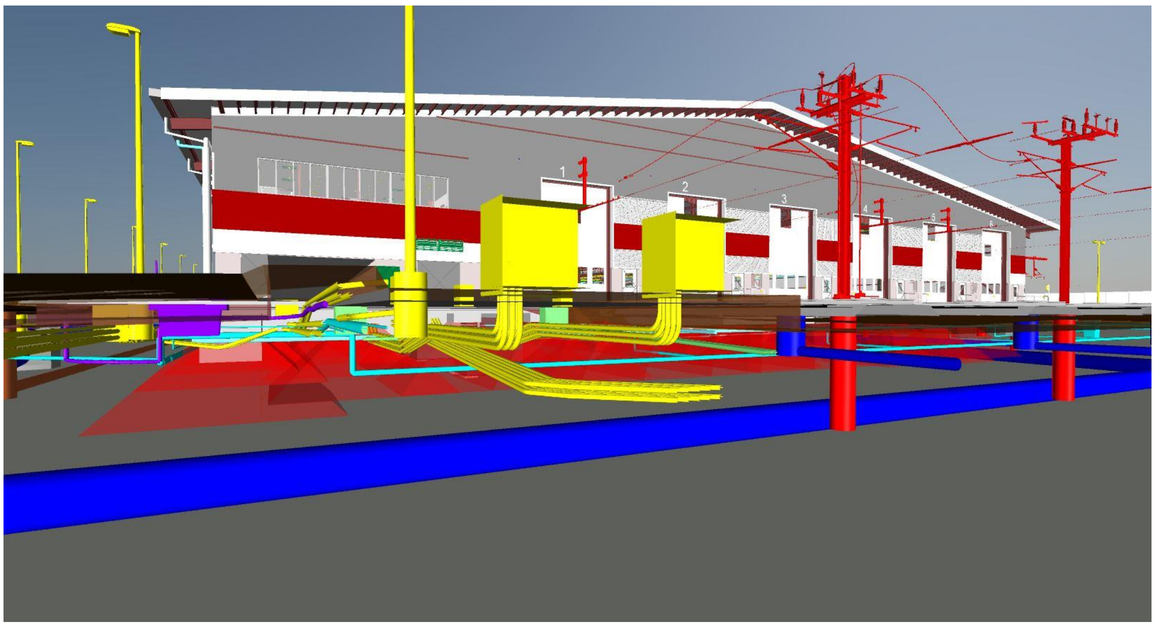


Figure 4 Model view used for coordination purposes

Design and construction - Coordinating construction drawings with BIM tools is much easier than with 2D drawings. In this sense, changes to elevations are reflected throughout the model. As a result, there is no need to sort through volumes of drawings in order to reflect a single change on the Master drawing document.

Construction - The value of BIM was considered visible in the design and construction phases of the project so far. It is also found useful in the coordination of assets, by connecting a BIM designed site to 12D software for instance for use in highly accurate machine automation.

Working off a single virtual environment on the NGR project has led to effective client-stakeholder-supply chain communication, planning and coordination; planning on the project has been through the use of Microsoft Project. This level of integration was attributed to the commonality that BIM provides the user groups and the steps taken to ensure prompt issue resolution.

On the NGR project, BIM has been exploited in improving stakeholder communication, the coordination of traffic movements to and from the project site, the zoning of the project and timely delivery of project resources to site.

There have been significant lessons learnt from comparisons between modelled and live project environments. Importantly, work on the model has been such that key parameters in the real projects have been given a priority based on their impact on the entire project timeline.

12.1.17. IMPROVED DATA AND INFORMATION MANAGEMENT

Design and construction - From its conception, members of different project teams have utilised and supplied information from different sources and in different formats. BIM provides a common basis for integrating all project information. As such, a high level of transparency and a deeper understanding has been promoted on the project site.

BIM platforms allow trained and approved (relevant) stakeholders to gain access to useful building information easily. Many BIM enterprise software are becoming cloud-based, in other words, a team member with appropriate authorisation can access information and even upload updates remotely without being physically on-site.

The capacity to combine a suite of different models into a federated model has also been a benefit of implementing BIM.

12.1.18. IMPROVED DOCUMENTATION QUALITY AND PROCESSES

Design and construction - The implication of cascading any change to a single component within a building model to every aspect of the model is the confidence that the information within the model is accurate and has not been changed elsewhere. Likewise, in project delivery, all team members working off the federated model do so based on some assurance that the information based around their work is accurate.

12.1.19. IMPROVED EFFICIENCY

Design and construction - Significant gains have been recorded on the project owing to a holistic integration of documentation processes with contractors' timelines, programmes, codes and work packages. This way, project visualisation of the model is tied in to actual project progress.

Construction - Each time onsite work is delayed or disrupted, there are significant cost implications. The use of the federated digital model has ensured that such changes are considerably less and where there is a possibility that change to initial plans will occur, ample responsive strategies are developed during the design stage to keep the cost implications for implementing change at a minimum.

12.1.20. IMPROVED OUTPUT QUALITY

Construction - The working mantra of BIM-based project delivery is, "if it can be designed, it can be built". As such, utilising BIM throughout the project lifecycle increases the certainty that well thought out project plans and designs can be followed through.

12.1.21. IMPROVED PRODUCTIVITY

Design - Because many of the design decisions are made using the BIM models, some project participants felt that they have gained significant savings in time. They contrasted, for instance, how much time it would take them to perform specific tasks on similar, traditional projects and were of the opinion that BIM eliminates a significant amount of design constraints using 2D methods as well as bureaucratic hurdles.

Design and construction - Because the project was procured on the basis of an Availability Payment PPP, there are liabilities associated with project delays. As such, contractors have leveraged the lessened delivery time that accompanies the use of BIM to ensure that project delivery is timely and at the prescribed level of quality.

12.1.22. IMPROVED SAFETY

Construction - By visualising particularly high risk tasks, project consultants have continued to simulate task implementations and have succeeded in writing safe work method statements to ensure risk-free implementation.

Whole safety procedures on the project have been developed around the implementation of activities considered to contain significant risk components by using the building model to simulate the implementation of the processes concerned. As such, the model continues to ensure that productivity gains derived from using BIM methods are secured through effective process visualisation

12.1.23. OPTIMISATION OF CONSTRUCTION SEQUENCE

Construction - BIM tools, such as Navisworks elaborate developed 3D models such that the sequence of the build can be determined by the project team and sequenced. Such meetings help to identify possible risk-inherent processes that would otherwise not have been identified.

12.1.24. REDUCED EXECUTION TIMES AND LEAD TIMES

Design and construction - Although it can be adopted irrespective of the project/contract type, BIM was thought to be particularly suited to the complexity of a fast-tracked project, notwithstanding the overlap of design and construction activities.

12.1.25. REDUCED RISK

Construction - The higher the accuracy of building information and built models, the less likelihood of encountering avoidable project risks; clash detection has been credited with risk-reduction strategies in BIM. Consequently, the delivery team can view the designed model; identify potential risks and work to eliminate those risk factors. Furthermore, BIM gives assurance that project processes are assigned to suitable project resources who take on the responsibility for ensuring accuracy and model integrity working together with other users of the model.

12.2. EXPECTED BENEFITS AND THEIR IMPLICATIONS

At the time of writing, there were four key benefits still expected to be achieved on the NGR project:

- improved decision making through the use of BIM for managing assets,
- improved models through BIM maturity,
- better utilisation of BIM for procurement on similar future projects, and
- new capacity to specify the content of BIM models within contracts.

As the project was under implementation at the time of the investigation, there was no conclusive evidence on how information from the digital models would be put to use after handover. It is expected that after the implementation stage of the NGR project and handover has been completed, the content of the federated model will be used during the operation stage for asset management. Maintenance works will draw on the data provided during the design and construction stages of the project to provide accurate infrastructural servicing. Therefore, decision making on the course of action to be taken regarding the product of the project will be objective and based on accurately collated information.

A cross-section of project team members were of the opinion that improvements in the use of the BIM repository were being attained with the incremental and accurate detailing of the content of the central model and associated sources of project information. As the contents of BIM repositories closely mirror the as-built facility during design and construction, project team members are better able to leverage the modelled information for informed decision making.

There were indications that some stakeholders would consider facilitating the procurement process in future projects using BIM tools and systems. This is consistent with proposals in the UK where procurement on Government-owned projects are expected to be supported through the use of Building Information Modelling.

Already, drawing on lessons learnt from current work on the NGR project, certain stakeholders have expressed a willingness to specify the content of BIM models within contractual documents. The motivating idea for such specifications is to avoid ambiguities regarding specific areas of concerns regarding the legal aspects of BIM such as: model ownership, data integrity, liabilities, etc.

12.3. UNREALISED BENEFITS AND THEIR IMPLICATIONS

The three benefits that were expected to have been achieved but not realised on the NGR project were: higher construction information quality levels, better alignment in design teams as well as project teams, capability improvements in measuring the impact of BIM on construction safety.

The ability of the content providers and the end-user (where the *end-user* in this context is the team member who needs information from other team members to develop an aspect of the federated model) is the common factor between the three factors. For instance, if the quality of the information that is produced for use in the central model is below a certain quality level, so too will the quality of the information produced from the federated model. As such, users of BIM data will need to invest sufficient time and resources to ensure the integrity of the BIM data. Also, with the possibility of exploiting building models to inform decisions regarding aspects of construction, such as in the production of safe work method statements, there is a growing need for BIM-literate project team members who can ensure that on-site safety is guaranteed by simulating all the possible scenarios associated with the implementation of particularly risky project activities.

12.4. ENABLERS

The following subsections provide profiles of the BIM drivers outlined in section 6. The discussion is based on the available case study data and examples shared during the interview sessions. Fully referenced verbatim accounts from the interviews are available on request, subject to the approval of the representatives of the New Generation Rolling Stock Project.

12.4.1.3D CONTROL AND PLANNING

Connecting a BIM designed site to 12D software for instance for use in highly accurate machine automation.

12.4.2.ASSET KNOWLEDGE MANAGEMENT

Interviewees expressed confidence in further benefits realisation on future BIM projects based on lessons learnt from prior projects. By recording the unique challenges experienced on the NGR Project, for instance, the stakeholders will be better able to respond to similar challenges should they occur on similar future projects, and by so doing, realise incremental benefits.

12.4.3.AUTOMATED CLASH DETECTION

A significant cost savings on the project is attributable to the tracking of clashes on the model. Project participants suggested that the knowledge of how changes anywhere on the project might result in possible clashes allows allowed resource owners take responsibility for ensuring that any clashes that result from their decisions are rectified.

12.4.4.COMMON DATA ENVIRONMENTS

BIM platforms allow trained and approved (relevant) stakeholders to gain access to useful building information easily. Many BIM enterprise software are becoming cloud-based, in other words, a team member with appropriate authorisation can access information and even upload updates remotely without being physically on-site.

12.4.5. CONSTRUCTABILITY ANALYSIS

The working mantra of BIM-based project delivery is, "if it can be designed, it can be built". As such, utilising BIM for constructability analysis throughout the project lifecycle increases the certainty that well thought out project plans and designs can be built.

12.4.6. COST ESTIMATION (QUANTITY TAKE-OFF)

By plugging in the elemental quantities generated through an automated quantity take-off to linked costing software, efficient budget management has been realised on the project.

12.4.7. DATA-RICH, GEOMETRICALLY ACCURATE MODEL COMPONENTS

Most project benefits realised so far are traceable to an early focus on working with the right information necessary for creating the digital model. In turn, accurate datasets have been credited with the effectiveness and quality of the eventual federated model in its capacity as a repository of digital project information. The higher the accuracy of building information and built models, the lesser the likelihood of encountering avoidable project risks.

12.4.8. DESIGN AUTHORING (3D VISUALISATION)

On the NGR project, the highly visual impact of the 3D digital model has eased interaction with clients.

12.4.9. DESIGN REVIEWS

Promoting a thorough understanding of the project scope from very early on during project design and consistently during meetings – leveraging the central model – has led to value gains reflected in the understanding evidenced by team members of the importance of their contributions in the context of the larger whole project.

Managing and resolving identified risks have had a direct impact on the minimisation of future costs associated with the manifestation of risks and the resource deployment in response. BIM has enabled the evidencing of probable risks, and the steps taken through risk management to reduce or completely eliminate their occurrence.

The BIM model has been heavily relied on during project meetings. Project team members gain a visual appreciation for their task requirements and, on that basis, are able to engage in productive, focused dialogue sessions with their supervisors, seeking clarification where necessary.

12.4.10. EARLY AND EFFECTIVE STAKEHOLDER ENGAGEMENT

By making early decisions on the expected outputs of deploying BIM on the project, clients' objectives and expectations served as input for actual design and construction, which in turn has resulted in the attainment of specific objectives.

As described in previous sections, using BIM on the NGR project has enabled project team members to track clashes. Identified early, these clashes are good indicators of potentially high to moderate risk incidents on the project. However, the identification of potential problem areas has not been restricted to the technical functions of the digital models; potential issues have also been identified as a result of model-enabled, collaborative discussions between the project's stakeholders.

A direct link between the BIM capabilities of consultants and benefit realisation was established from the interviews. Effectively, when consultants know how to drive value by exploiting BIM, there is evidence that BIM benefits can be realised from very early on as has been the case on the NGR project, specifically in relation to some benefits highlighted earlier, such as: the management of clients' expectations, improving client feedback, model-based stakeholder collaboration, change management and clash management.

Where problem spots and potential issues have been highlighted, owners are delegated the tasks of developing risk response strategies as well as safe work method statements around the activities concerned. This has ensured timely resolution of problems on the project.

12.4.11. ENGINEERING ANALYSIS

Leveraging BIM has facilitated the design and integration of engineering elements – Mechanical, Electrical and Plumbing (MEP) – with civil and structural elements. As a result, the visible MEP connection points are utilised to facilitate detailed and bulk modelling of civil works (Figure 5).

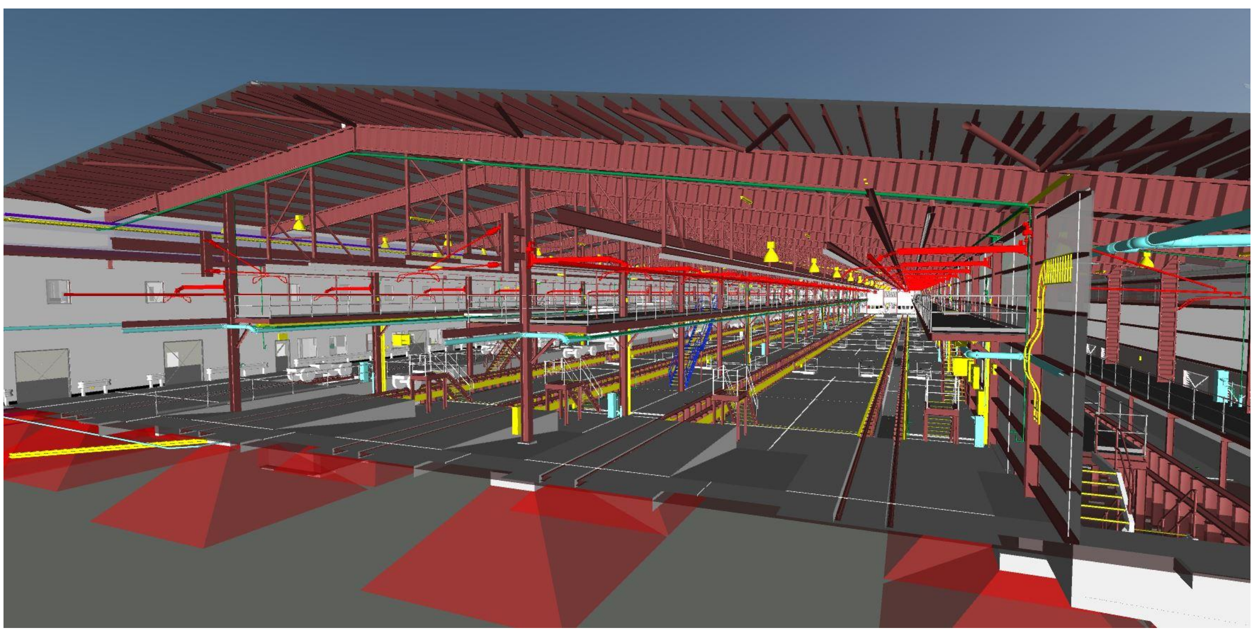


Figure 5 View of the model highlighting MEP elements

12.4.12. FRONT-END PLANNING

On the NGR project, an eye for the end product and its management was considered a core enabler to the design and on-going implementation work. For instance, data sourcing and information management while developing the federated model has been with a view to their use during post-handover facilities management.

12.4.13. GIS-BIM

On the NGR Project, connecting GIS Data embedded within the federated model to 12D software has been used for machine guidance.

12.4.14. INTEGRATED MODEL AND PROGRAM MANAGEMENT SYSTEMS

The core attribute of federated models is their function as hubs of linked project information. On the NGR project, information from other software platforms, e.g. Primavera (P6), linked to the digital model has resulted in improved project management and planning.

Version updates and clash detection are highly relevant BIM functions that lend significant value to project change management. Given that the stakeholders work based on a single federated model, necessary changes to the digital and non-digital contents of models are quite easily implemented tracked, and managed.

Coordinating construction drawings with BIM tools is relatively much easier than with 2D drawings. In this sense, changes to elevations are reflected throughout the model. As a result, there is no need to sort through volumes of drawings in order to reflect a single change on the Master drawing document.

12.4.15. ONLINE COLLABORATION AND PROJECT MANAGEMENT

Many of the problems associated with the coordination of design information under traditional settings were absent on the NGR project. BIM-enabled project delivery promoted transparency and information sharing that has been crucial to the timely implementation of team members' activities on the project.

12.4.16. PHASE PLANNING (4D MODELLING)

In addition to sequencing the build process using BIM tools, the time dimension can also be modelled and simulated using 4D BIM tools such as Navisworks.

12.4.17. VIRTUAL WALK-THROUGH AND ANIMATIONS

By using BIM platforms, the entire project build can be simulated through a range of different techniques, including: fly-throughs, walk-throughs, activity sequencing, etc. Whole safety procedures on the project have been developed around the implementation of activities considered to contain significant risk components by using the building model to simulate the implementation of the processes concerned.

13. CONCLUSION

This research was conducted with a view to addressing six underpinning questions, namely:

- How does the current use of BIM contrast with traditional (2D) project delivery methods?
- What do stakeholders with first-hand BIM experience consider as the benefits of BIM on their projects?
- How are those benefits realised? That is, which features or tools act as drivers?
- Are there internal project or organisational goals related to BIM benefits?
    - If so, what are they or what might they be in the future?
- What are the impacts of BIM on the procurement process?
- What is a valuable way of presenting the final SBEnrc Project 2.34 output in order to serve as a practical tool for practitioners?

In response, the full report provides the following:

- A discourse of the features of BIM-enabled design and construction that distinguishes it from traditional project delivery methods.
- At least 25 unique examples of how BIM has been beneficial to the NGR project provide ample evidence for a contrast between BIM-based and traditional project delivery methods. These benefits include improved communications and coordination leading to higher customer satisfaction and improved output quality.
- 17 tools and processes which serve as key enablers for the realisation of BIM benefits are discussed summarily. These tools include common data environments, cost estimation, 4D modelling, GIS-BIM and front-end planning.
- A discussion of how organisational goals determine BIM deployment and application.
- 32 useful tips/lessons for managers derived from the NGR Project as well as from other shared experiences of the stakeholders; presented as lessons learnt.
- A critique of the expected and unrealised benefits identified during the investigation.
- Suggestions on a range of strategies for presenting the final outputs of SBEnrc's Project 2.34 in a way that would be useful as a managerial tool for BIM practitioners.

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15. APPENDICES

15.1. APPENDIX A: INTERVIEW QUESTIONS

This section presents a list of the interview questions, most of which can be found in the research protocol. It should also be noted that the wording of some of the questions might have been slightly changed with respect to the research protocol to make them more explicit.

1. Can you please tell me about your role and how it relates to the use of BIM on the NGR project?
2. Do you have internal objective performance measures related to the use of BIM and its benefits?

   a. If yes - Does ORGANISATION'S NAME track and record progress towards those BIM goals?
3. Is this done through KPIs?
   a. If yes – what are they? Do you think there are other KPIs that should be also used? And have you monitored ROI from BIM? Which type of documents would you use to monitor these indicators? Could you share with us any documents that have information regarding project BIM success criteria, understanding data being collected at each stage, and standard being used?
   b. If not – in your opinion, are there any KPIs that you think should be used?
4. Were you involved in the tender process?
   a. How was your experience during tender and procurement in relation to the implications of the use of BIM?
   b. Did you have access to guidelines that were useful? Who provided them?
5. How are suppliers' and sub-contractors' performances assessed?
6. How embedded is the supply chain in the use of BIM?
7. In your opinion what are benefits of implementing BIM in the procurement of public *building and infrastructure assets*? Especially based on your experiences in the NGR project:
   a. What tools or processes do you think have enabled you to achieve these benefits (go over each benefit mentioned)?
   b. If you were to try to find evidence of these benefits, what would that be? Would there be any indicators?
   c. Can you think of any other benefits which would probably be achieved later or might have been achieved if something was done differently?
8. If you were to start again, knowing that these benefits are your goals, what would you use to measure your progress in achieving those benefits that you mentioned?
9. If you were to do it all over again, would there be anything that you would do differently?
10. Is GIS supporting your Digital Engineering workflows, and if yes - what data goes into the GIS?
11. Which type of documents would you use to monitor these indicators?
12. Could you share with us any documents that have information regarding project BIM success criteria, understanding data being collected at each stage, and standard being used?
13. How will the integrity of the data and version control be managed?
14. What role has 2D and 3D data visualisation played in the project?
15. In your opinion, what are benefits of moving from 2D traditional ways of working and implementing 3D integrated project environments such as BIM in the procurement of public building and infrastructure assets? Especially based on your experience with the New Generation Rollingstock Project:
    a. How has collaboration been achieved?
    b. What data standard was used - e.g. BS1192? (BS1192 specifies the procedures for the management of construction information *production*, *distribution* and *quality*, including CAD-generated construction information)
16. In your opinion, do you think the available project contract models are appropriate?
    a. If not – what should be changed?
    b. If yes – what other models do you think may be better suited?

17. We are developing a framework to assess the benefits of BIM across the project life-cycle, as a BIM stakeholder what do you think would be a useful form for that framework to take?

15.2. APPENDIX B: OVERVIEW OF SOFTWARE ADOPTED ON THE NGR PROJECT

This section provides short descriptions of the software tools referred to within the body of this report.

15.2.1. REVIT

Revit is a building information modelling (BIM) software product from Autodesk. Aimed at professionals in the AEC, Revit has been deployed for use in facility lifecycle stages ; design, construction, facilities management and demolition (Autodesk, 2015). Within Revit platforms, users are given access to an object repository containing: 2D drafting components, 3D elements and families and plug-ins that are 4D-enabled.

15.2.2. 12D

12D is a multi-platform software employed extensively in the modelling of in-ground services and terrains as well as in complex civil infrastructure projects (12D, 2015). Other areas of its application include: rail, mining, surveying, construction and airport infrastructure modelling.

15.2.3. MICROSTATION

As a software and discipline-specific tool, MicroStation is used in the AEC for infrastructure modelling such as: rails, buildings, bridges, etc. An important highlight of the software is its flexibility in that it can be used as a standalone software, as well as a technology platform that fosters integration with other [supported] software applications (Bentley, 2015).

15.2.4. MICROSOFT PROJECT

This is a primarily a project management software product which is a component of the MS Office suite of applications. Microsoft Project is mostly employed in coordinating through project planning and control; team communication is enhanced by this (Microsoft, 2015). Functions that are particularly useful in deploying Microsoft Project are: resource allocation, project planning, progress tracking, resource loading and budget management.

15.2.5. PRIMAVERA

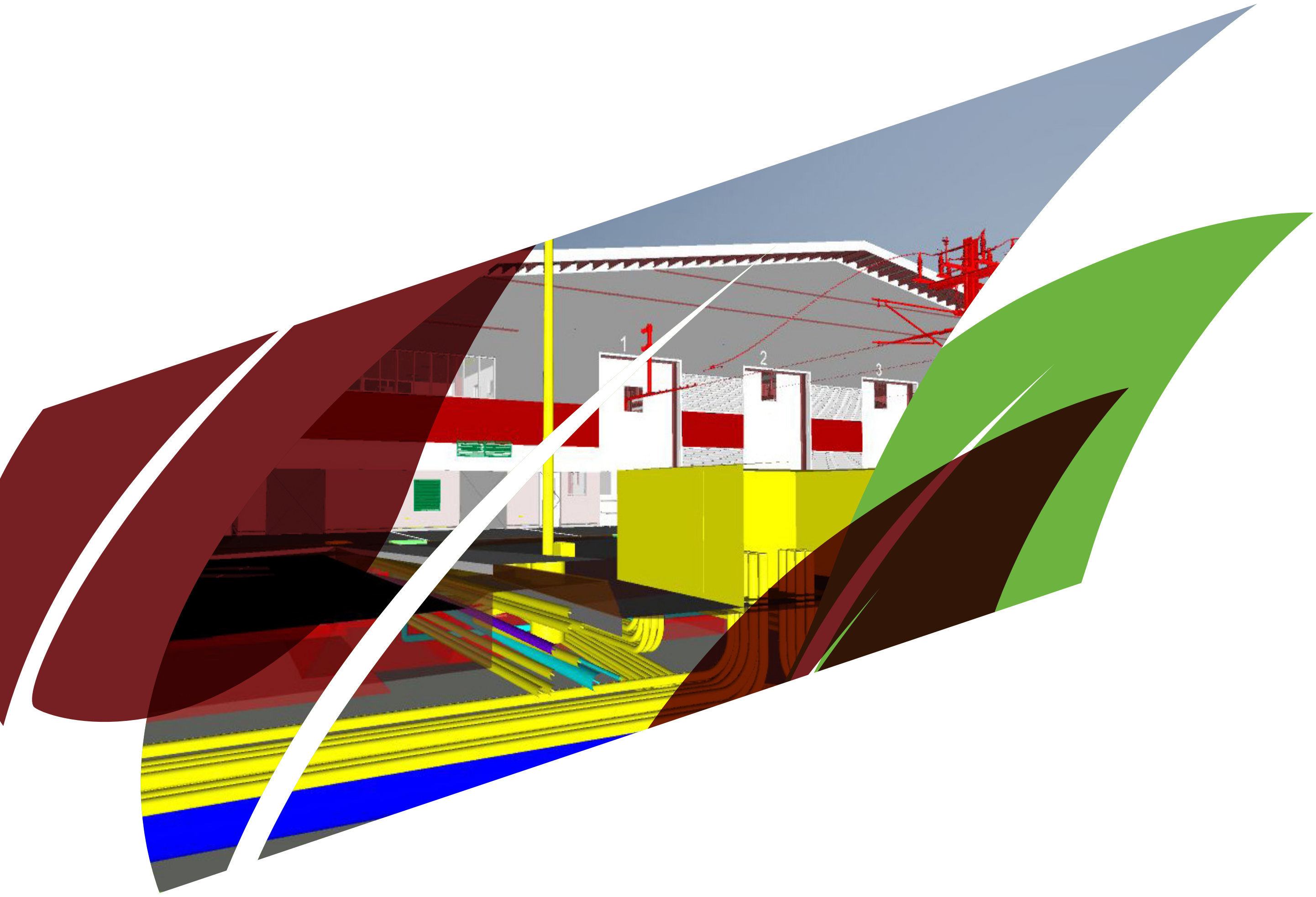
Primavera is an Enterprise Project Portfolio Management software produced by Oracle Corporation. Primavera's capabilities that are predominantly employed in the management of projects include: its use as a repository for project resources and their capacities, project planning information, change impact assessment, cost implications of changes, progress with respect to goal realisation, exploiting lessons learnt databases (Oracle Corporation, 2015).

15.2.6. NAVISWORKS

A product of Autodesk, Navisworks is an integrative 3D and 4D software tool. It has the capacity to combine various 3D models within its platform and enables AEC professionals to perform several project functions, including: schedule optimisation, process simulation for construction projects, interference/clash coordination and management (Autodesk, 2014b).

15.2.7. AUTODESK 360

Although it is not a model creating software tool, Autodesk 360 provides a centralised cloud-based platform which enables data searching, viewing, and sharing among project stakeholders (Autodesk, 2014a).



This research would not have been possible without the ongoing support of our industry, government and research partners:

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September 2015