PERTH CHILDREN'S HOSPITAL

CASE STUDY REPORT

Sustainable Built Environment National Research Centre

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This report summarises the findings of the Perth Children's Hospital (PCH) case study carried out as part of SBEnrc Project 2.34 *Driving Whole-of-life Efficiencies through BIM and Procurement*. This case study is one of three exemplar projects studied in order to complement Centre's industry-focused research. The aim was to identify indicators for measuring tangible and intangible benefits of Building Information Modelling (BIM) across a project's life-cycle in infrastructure and buildings.

The PCH is an AUD1.2 billion project carried out under a two-stage managing contract model between the Government of Western Australia and John Holland. The project used BIM for the design and construction of the hospital and has required a facilities management BIM model as a key deliverable. The case study drew information from a series of interviews with BIM managers across different stakeholders as well as project documentation.

The research identified 26 specific benefits from using BIM. Each benefit was then profiled based on the information provided by the case study data. These benefits were enabled by 20 different tools and processes related to BIM, including software tools as well as governance processes such as co-location and frequent project team meeting.

Although one of the objectives of the case study was to identify BIM metrics currently used in this project, only one metric was found at this stage of the project. However, 20 different metrics to measure benefits from BIM were identified by interviewees as with potential for use in the future.

This case study also provided insight into challenges associated with implementing BIM in such complex projects as well as issues related to procurement and asset management, along with lessons learned for design, construction and asset managers.

1. ABOUT THIS REPORT

This report presents the findings from:

- Interview series carried out at the Perth Children's Hospital (PCH) in accordance with SBEnrc Project 2.34 internal Research Protocol and Communications documents (unpublished).
- Documents analysis of key documentation provided by PCH representatives and interviewees.
- BIM uses form completed by three BIM managers across design, construction and asset management functions. This report is solely based on the outlined information sources.

This report is organised as follows:

- Sections 2 and 3: Provide the context for the results.
- Sections 4 to 10: Sections 4 to 9 present a summary of the main conclusions from the interview and document theme analysis. Section 10 provides profiles for the benefits and enablers shown in Sections 4 and 5.
- Section 11: Provides the reference codes used for the verbatim extracts in the appendices and other references.
- Section 12.1: Presents the interview questions.
- Section 12.2: Provides short descriptions of specific software solutions mentioned throughout the report.

2. ABOUT THE CASE STUDY

In general, this research seeks to answer the following 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 Key Performance Indicators (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 other 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 aimed to gain insight into the uptake of Building Information Modelling (BIM) in complex projects during the construction stage. However, the PCH used a Design and Construction Managing Contractor delivery model and therefore it was expected to provide some insight into the design state as well. Eight interviews with Project Managers and Directors with roles related to the use of BIM across client, consultant and contractor firms were carried out during the period of 24-26 November 2014. Their roles ranged from hands-on BIM development and management to basic BIM usage for procurement, auditing and approval processes. The interviewees represented three stakeholder groups: client, contractors and consultants.

The interviews aimed to understand:

- How is BIM currently being used vs 2D traditional delivery methods?

- What are the perceived benefits by different stakeholders with first-hand experience?
- How are those benefits realised? (i.e. which features or tools act as enablers)
- Whether there are internal project or organisational goals related to benefits from using BIM? and what are they or might be in future?
- What is the effect of BIM on the main contract procurement process? (including barriers, challenges that might hinder benefits, access to standards and guidelines that are useful, training and skilled personnel as well as contracting, approval processes, etc.)
- What form should the final SBEnrc Project 2.34 output take in order to be a practical tool for practitioners?

In addition and prior to the interviews, a document was circulated to Project Managers that have roles directly related to the current and planned use of BIM in design, construction and asset management. The document requested participants to select BIM uses currently implemented or planned for future phases at the PCH. This information was used mainly as background information for the researcher carrying out the interviews and therefore is not presented in this report.

After the interviews were carried out, the research team received several documents mentioned during the interviews, either from the interviewees directly or from the PCH representatives. These documents included contract guidelines and schedules as well as lessons learned reports. The research team also received clarification from the client on specific information which was considered ambiguous or identified as incorrect by PCH representatives.

This research is being carried out under a confidentiality agreement with the Government of Western Australia and therefore the findings presented in this report are anonymised and have also been reviewed and approved for public distribution by a designated representative of the PCH.

This report also includes information that although does not relate directly to the questions used for the interview, was deemed useful towards achieving the overall research project objectives expressed in the project schedule and research protocol.

3. ACKNOWLEDGEMENTS

SBEnrc would like to express its gratitude to the Government of Western Australia 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 across the three stakeholders group 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.

SBEnrc would also like to acknowledge PDC Group for providing some of the information and images used in this report.

4. ABOUT THE PERTH CHILDREN'S HOSPITAL

This AUD1.2 billion project will replace the Princess Margaret Hospital as Western Australia's dedicated children's hospital to provide the best possible clinical care for future generations and as a location for outstanding paediatric research. The hospital project team has endeavoured to carry out extensive consultation and research to benchmark their work against national and international best practice in design and service models. This landmark project is a cornerstone of the Western Australian State Government strategy to deliver major social infrastructure for future generations.

Procured as a Two-Stage Managing Contract (MC), the project is currently being carried out under a fixed price MC awarded to John Holland Pty Ltd at the end of Stage One. The Stage One design development and external subcontract pricing was carried out in parallel with early works and ended in December 2012. The PCH Managing Contractor is responsible for design and construction. This project is under construction, well into Stage Two and due for completion in late 2015. The project completion date has been extended due to increased scope.

Figure 1 Perth Children's Hospital (Government of Western Australia Department of Health, 2015)

4.1. TWO-STAGE MANAGING CONTRACT

The MC requires that 80% of the value of the project works be designed and tendered prior to the submission of the Stage 2 offer. This means that there is still 20% of the value not fully designed and market priced by the Contractor when the Stage 2 offer is submitted. This results in the Contractor having to complete a material element of design during Stage 2. This type of contract has been seen by the State as a way of managing their exposure to rapid cost escalation in projects such as the Fiona Stanley Hospital which opened in December 2013 in the Perth Southern Suburb of Murdoch (WA Department of Treasury, 2014).

The PCH MC contract document provided for some shared responsibility during Stage 1. The contract originally contained an element of risk/reward sharing for Stage 2. However, the Contractor made a second lower cost alternative offer at Stage 2 which was accepted by the State and moved all the risk and reward to the Contractor. Figure 2 provides a map of the organisations involved in the PCH project.

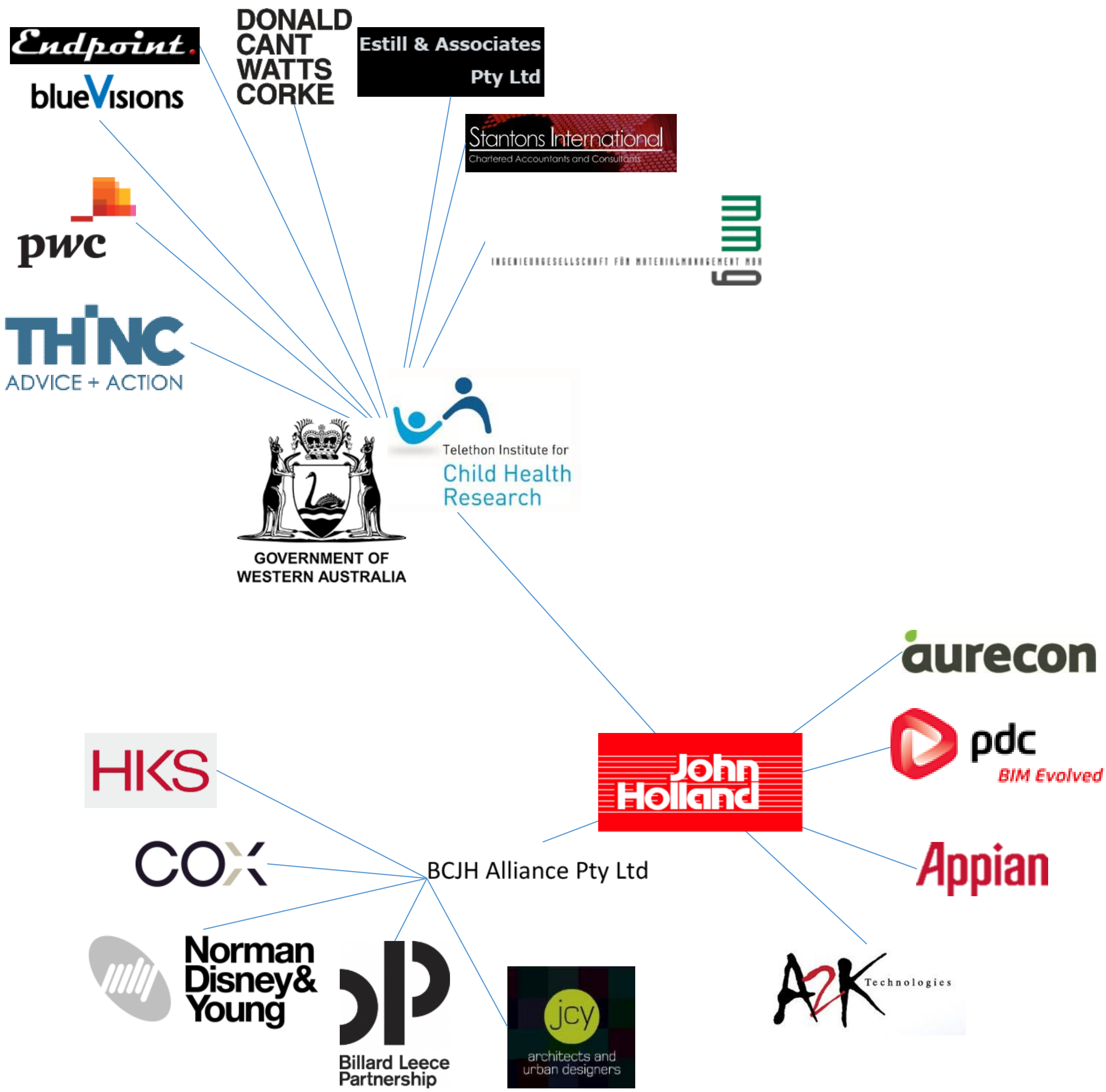

Figure 2 Organisations involved in the PCH project

4.2. BIM FOR WHOLE-OF-LIFE ASSET MANAGEMENT IN THE PCH

BIM is defined in PCH documentation as a *process focused on the development, use and coordination of a digital information model of a building project to improve the building design, construction, commissioning, operation and maintenance*. BIM is required to be used for all building systems design, development and analysis, including but not limited to architectural, interiors, structural, mechanical, electrical, plumbing, fire suppression, civil and landscaping.

Key drivers for the client to require the use of BIM were:

- Decision making in complex multidisciplinary projects is now based on data and information management rather than traditional project management[1].
- BIM can help drive efficiency, realise cost savings and increase the value of whole capital project life-cycle development process.
- Setting an example to other WA organisations to demand more of its partners by demonstrating the benefits that can be realised by embracing technology.
- The belief that owners are ultimate beneficiaries and must remain involved in the development process and drive change until it becomes self-sustaining.

During concept design and developed design stages, BIM technology and processes were to be used to develop and establish building performance and the basis of design in accordance with the client's standards. The models are required to be interoperable with analytic tools for, including but not limited to, building envelope, orientation, daylighting, energy consumption, Building Management System (BMS), renewable energy strategies, life-cycle cost analysis, and spatial requirements.

The BIM model is composed of individual models which have been broken down according to a work breakdown structure developed by the contractor and all submittals are required to be extracted from these BIM models.

The project established a series of BIM-related objectives:

1. To have visually fully fitted out spaces that would help the decision-making process. This was achieved by using virtual walk-throughs and predefined camera positions.
2. To facilitate model coordination and a collaborative project environment. This was achieved through regular BIM managers review meetings.
3. To facilitate effective and accurate analysis including cost and construction scheduling. This project used information extracted directly from models and created collaboratively.
4. To find and resolve all major spatial coordination issues between elements before construction begins. This was achieved by using project collaboration tools and clash detection.

[1] Traditional project management disciplines of monitoring and managing time, cost and quality have not been abandoned. However, this project recognised that the industry needs new tools to deal with the quantum of information now available. This was seen as particularly important as "fast track" projects become the norm. To maintain momentum, decisions must be made very quickly and a mechanism was required to efficiently process and present large quantities of data as inputs into the decision making process.

5. To track and control construction information and schedules by managing the construction process through the use of BIM and associated data. This was achieved by including appropriate information and cross-referencing with construction sequence.
6. To be able to maintain data integrity of all Furniture, Fixtures and Equipment (FF&E) data throughout the asset's life-cycle. This is being achieved by aligning BIM FF&E systems so they can use the same database across the asset life-cycle.
7. To produce a facility maintenance model based on as-built information. This is being achieved by updating the BIM model throughout the construction process. Additionally, each model element contains maintenance data based on coordinated input from all stakeholders. The as-built model will also include shop drawings provided by sub-contractors.
8. To maintain data integrity. This is ensured by guaranteeing easy access to data by the client and end-users.
9. To eliminate re-work during handover. This is being addressed by ensuring that the same model can be used throughout the asset's life-cycle including ongoing maintenance.

The PCH project also requires a whole-of-life report to be delivered within the BIM model and format. This report includes key information such as: expected life of materials proposed, replacement schedule and estimated cost; practical replacement strategy for material and equipment including likely disruptions to be incurred when replacing equipment; estimate energy cost over 30 years based on different plant and equipment options; and estimated maintenance cost over 20 years.

This project also emphasised the need for close collaboration across stakeholders in order to achieve the effective use of BIM to its highest level. These efforts included BIM workshops and management/coordination meetings, pre-defined office requirements that take into account the technical needs of developing the BIM (e.g. hardware and staff requirements), establishing and documenting model exchange processes, conduct pre-tender briefings, and using a colour code for clash detection, among others.

The coordination process was facilitated by the use of a federated model[2]. This approach can help reduce file size issues, allow specialist sub-contractors to use their current 3D CAD packages to coordinate and fabricate their installations (BIM-MEP AUS, 2014), increase transparency and maintain the lack of privity of contract (Lowe & Muncey, 2009).

5. BIM BENEFITS

Tables 1-3 summarise the benefits of using BIM identified in this case study. Most benefits have been classified according to the Benefits Dictionary available in the book to be published in early 2016 *Delivering Value with BIM- A Whole-of-life Approach*. Benefits have been separated into: experienced, expected and unrealised. The first refers to benefits that have been either personally *experienced* by interviewees and/or identified in project documentation for PCH project thus far; *expected* refers to those benefits which have not been experienced yet but are expected in the near future based on

[2] A Federated Model can be defined as *a 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* (Lowe & Muncey, 2009).

planned BIM uses; and *unrealised* refer to benefits that the interviewees had expected to experience based on other projects but were not achieved due to project-specific challenges.

The benefits are presented in alphabetic order. Short profiles of each benefit can be found in Section 11.1 and provide information about the phase at which they were experienced or expected to be realised as well as examples.

- Better change management
- Better cost accounting
- Better data/information capturing
- Better programming/scheduling
- Better scenario analysis
- Better space management
- Better use of supply chain knowledge
- Competitive advantage gain
- Faster information exchange
- Force people into changing design thinking
- Higher process automation
- Improved communication
- Improved data and information management
- Improved documentation quality and processes
- Improved efficiency
- Improved learning culture
- Improved programming/scheduling
- Less rework
- Improved project coordination
- Improved output quality
- Improved safety
- Lower cost
- More accurate quantity take-off
- Reduced lead times
- Reduced project execution time (with respect to the same circumstances but using traditional methods)
- Reduced risk

Table 1 Summary of experienced benefits ([¥] not in Benefit Dictionary)

- Asset management labour utilisation savings
- Better cost accounting (AM)*
- Improved data and information management (AM)
- Improved programming/scheduling (real-time)

* Asset Management (AM)

Table 2 Summary of expected benefits

- Automated engineering calculations regarding the impact of changes on specific areas[‡]
- Better cost accounting during operations
- More prefabrication[‡]
- More sustainability related benefits[n]
- More integrated multi-asset management[¥]
- Shorter delivery time and lower cost (with respect to ideal circumstances)

Table 3 Summary of unrealised benefits.[‡] Can be categorised under higher process automation; [n] Can be categorise under better environmental performance. [¥] Not in the dictionary.

6. BIM BENEFITS ENABLERS

This section presents tools, actions or processes that were identified by interviewees as associated to or required in order to achieve specific benefits from implementing BIM. Please note that not all of these enablers are currently being used in the PCH project, but may include tools used experimentally for specific sections of the project or planned to be used in the near future. Short profiles of these enablers can be found in Section 11.2, including examples of how they were used and their relation to specific benefits.

• 3D visualisation and animation • Asset management system interface • Automated clash detection • BIM-enabled surveying software • BIM management and collaboration software • Cloud storage and integrated data management systems • Code-checking and validation • Co-location • Data integrity and data rich integrated models • Data reconciliation tools	• Frequent project team meetings • Health and safety simulations • Integrated program management tool • Issues and project tracking software • Project logistic tools (4D) • Project review software • Radio frequency and unique identification • Smart hand-held devices • Solar, wind, acoustic and thermal analyses • Well-structured data

Table 4 Summary of benefit enablers

7. BIM BENEFITS METRICS

Defining metrics for BIM benefits was considered difficult because so many benefits are intangible or can only be monitored qualitatively. Additionally, benefits depend significantly on the specific project type and conditions. It was the opinion of the interviewees that for measures to be relevant they must be accompanied by an analysis of the context for different levels of performance. They should also be flexible enough to select only those which are relevant to the current project as opposed to a "one-size fits all". It was also pointed out that BIM is a new way of working and therefore it is very difficult to measure benefits from it, that it would be equivalent to measuring benefits from using the internet.

To measure and benchmark benefits (particularly financial benefits) projects would need to be classified by type and value in order to be comparable. The benchmarks' starting point would have to be outcomes under traditional methods. Establishing these metrics would be most beneficial once the industry is more BIM-capable, otherwise low performance could be wrongly attributed to BIM instead of lack of skilled personnel.

Nevertheless, having a framework to monitor benefits and compliance was considered important for future contracts as well as being able to audit all parties as part of the BIM governance process. This could help ensure compliance to the BIM strategy, structure and standards. Having maximum levels could however be counterproductive, leading to missed opportunities for innovation.

7.1. METRICS USED IN THE PERTH CHILDREN'S HOSPITAL

There are no formal metrics for benefits or capabilities currently being implemented that were identified by the interviewees or the documentation provided. The only metric is to deliver a asset management model with all requirements outlined in the contract document Schedule 4 and supporting documents. However, the project does have BIM-related goals as shown in Section 4. The reason for this is that BIM was a new way of working when the project started and it was unclear what was possible. The initial idea was to use the project as a learning process to serve as basis for future projects using BIM. Since then some stakeholders have developed workflows and can track certain measurable deliverables related to benefits from BIM.

More recently, it has been possible to create reports with KPIs related to BIM capabilities and issues. Among other things these reports contain number of clashes, number of anomalies per item, number of variations, and reasons for changes.

One of the stakeholders started to keep record of what they considered benefits from BIM based on anecdotal data. For example, when an issue was resolved they recorded how much time the person who resolved it would have expected to invest if using traditional methods based on his/hers professional experience with regards to how much time it took using BIM. However, this effort was discontinued because the data would not be publishable due to confidentiality agreements and it eventually became too difficult.

7.2. SPECIFIC METRICS

The following were metrics suggested by the interviewees to measure the benefits achieved from implementing BIM:

- Milestone BIM-related deliverables (# drawings delivered on time)
- Number of man-hours
- Number of resources needed for specific tasks – in conjunction with man-hours
- Program compliance
- Smart clash reports
- Asset management element audit
- Asset management/smart hand-held device interface audit
- Data accuracy
- Energy use (watts per square metre) vs modelled and savings across life-cycle
- Amount of rework
- Number of drawings made in a period of time vs traditional projects
- dRofus[3] logs
- Cost associated with registering, validating and responding to Requests for Information (RFIs)
- Number of RFIs
- Number and time required for resolution of issues register in the Job Issue Register (JIRA)[4]
- Saved time in preparing documents for handover and commissioning
- Surveys and other qualitative assessment
- Error rate (# of site surveys) through Trimble[5] logs

[3] Product description can be found in the Appendix or go to http://www.drofus.no/en/
[4] After the interviews the research team was informed that JIRA resolution is already tracked on the project.
[5] Product description can be found in the Appendix or go to http://www.trimble.com/

- Cost of design process vs usual
- Using elements of BIM in furniture, fixtures and equipment (FF&E) through dRofus; volumes, locations, equipment time, re-siting and placing, equipment, and space management.

8. BIM, PROCUREMENT AND ASSET MANAGEMENT

This section summarises those topics and lessons learned highlighted by interviewees or documents analysed that relate to BIM in procurement and asset management. Although some comments were specific to the PCH case study, some of these lessons learned are based on the interviewees' long-standing professional experience across a number of projects which have used BIM and are meant as a "word of advice" for other managers. It also includes information about how some of these issues have been dealt with in the PCH project.

- Formats: the project team is currently producing IFC files for dRofus and PDF files for the document register. Although the original contract did not request Revit[6] files, they will be delivered at the handover phase as per the reviewed terms. Some sub-contractors still require using 2D formats due to lack of BIM capabilities and competencies.
- Contract: Schedule 4 is being used to define the design and construction deliverables. Although originally developed for paper-based projects, it is now being modified in order to be used for future BIM projects by the State. The ultimate design documentation deliverable for PCH is still undefined but is likely to be influenced by the requirements of the new Agility Facility Management system procured by the State.
  In general, it was stated by interviewees that contract documentation must consider the fluid nature of technology and fast rate of change. It was also highlighted that the level of detail of documentation that outlines BIM deliverables increases through the different project phases. It however needs to map the processes and expectation from the start. It was also mentioned that in the Australian industry there are often conflicts because the contract doesn't explicitly state that the model and IP will be owned by the client at the end of the project. This can normally limit collaboration and creates rework between phases.
  However, the PCH contract clearly states that the client owns all outcomes from this project. This includes photorealistic renders of the external design and key typical internal views; full size spatial inpatient and consulting mock-up rooms, including all furniture; details of design aspects that address outstanding issues from previous design phases; description of all functional areas; details of major plant systems, and all relevant drawings and schedules, to mention some.
- Asset management requirements: it was observed that data accuracy and relevance is very important to use BIM in built asset and facility management. This requires the client knowing what information they will require during operation from earlier project phases and setting constant information updating processes. It also requires different software and datasets interfacing which can be challenging. It was highlighted that it is useful to include prompts in the asset management system so users are required to update the model before closing an issue.
  The PCH asset management requirements are driven by practical and outcome-based considerations. Examples include requiring that the BIM model can be integrated with the documents, works and building management system; and that it can be used for way finding

[6] Product description can be found in the Appendix or go to http://www.autodesk.com/products/revit-family/overview

and viewing elements which may be hidden. Data required to be provided for maintenance in the BIM model includes maintenance schedules, consumables, and room datasheets; all of which is also required to be in a format that is transferrable into State's health facilities management system. It also requires the use of OmniClass and Unique[7] element numbers or equivalent category classification.

The Project BIM Manager is responsible for making sure that the above is achieved by coordinating project teams to ensure the correct data is collected for the facility management model. This role is also responsible for facilitating and establishing requirements for data transfer to the facility management model.

- Access to information: it was considered that the client often needs to rely on the expertise of consultants and advisors in order to realise most benefits.
- Skills level: workshops and training courses have been developed for client managers and senior staff and sub-contractors. This induction provides a basic level of skills required to understand, mine and manipulate the model to fulfil their function. The overall skills level of the workforce was considered to be increasing, allowing organisations to source staff with BIM experience as it becomes more mainstream.

  Training and development is also considered a key part of the successful implementation of BIM for asset management. During the project, the BIM Manager was responsible for all managers being BIM capable and trained appropriately. Additionally, the user group was to have access to a toolkit which aimed to demystify some of the elements of working with BIM.
- BIM nirvana: the ideal asset management system will be smart and include the use of mobile hand-held devices, be data-rich and have an easy interface between the information in BIM and the asset management systems.
- Generational change: moving to this kind of paperless technology is important for attracting and retaining new generations to this field of work.
- BIM from early phases: project staff highlighted the importance of starting to think about BIM and mapping out the governance and processes from the project business case or early design phase with the end goals in mind. It was also mentioned that it would be important for future projects to set all the standards and naming conventions at the start of the project life-cycle. Additionally, all parties should have clear understanding of these conventions and what inputs are required of them. This would avoid duplication, ambiguity and errors. Clear frameworks and protocols should also be set from the start. It was the opinion of one interviewee that if clients were to develop tender models, this would reduce the tender price of this type of project[8].

  The current version of Schedule 4 establishes BIM as the only project design medium and provides a number of specific requirements regarding formats, BIM uses and detail design program in terms of Levels of Development.
- Streamlining procurement: BIM is being used for tender and pre-tender briefing. Approvals are also being done through the model. It was considered that cost and procurement can be facilitated through the use of BIM if the model matches the requirements of the costing and procurement systems. This includes units of measure, modelling practices and level of accuracy, and need to be agreed upon by the project team.

[7] *OmniClass and Uniclass are well known industrial standards. These classification systems have been utilized in various construction information management practices such as constructability information and document classification* (Park, et al., 2013).

[8] This was not done for the PCH, tenderers were only provided with a functional and technical brief. The contractor was then solely responsible for both design and construction tasks.

- Continuity: Successful outcomes can be enhanced by ensuring that the BIM strategy and processes are integrated and consistent with the overarching project delivery and asset operation strategy. This is independent of specific project BIM deliverables.

9. PROJECT CHALLENGES

- Lack of BIM skills and capabilities: this was the main challenge identified by interviewees for design and architectural staff, asset managers, procurers, operators, suppliers and sub-contractors. This has improved recently in certain disciplines but it is still limiting the realisation of benefits and creating inefficiencies, and it is seen as a regional challenge rather than just a project challenge. This has been acknowledged by the project team who is taking steps towards reducing that gap before handover. It was observed that in order to realise the largest section of the benefits over the life-cycle of the asset, operators must gain these skills and capabilities in order to maintain the model up-to-date and useful.
  This challenge was also found in the documentation, with issues arising from the incorrect use of certain software packages due to lack of skills and competencies, creating an additional cost.
- Software limitations: there is no single BIM software solution available in the market that covers all BIM uses. In the PCH, the team has had to develop and purchase a number of software packages and plug-ins to achieve all the functionalities that were desired such as change management and tracking. They have also found that software used by manufacturers is often not compatible with Revit, creating rework.
- Hardware limitations: sections of the project team had to update their computer hardware to access the model. The capacity of the server to handle data has also been a challenge at times due to the large number of people in the local network and volume of data.
- Buy-in from different stakeholders: mainly identified as a challenge with builders for health and safety modelling, and operators for asset management. In particular for asset managers, it was highlighted that without fully understanding what the potential uses for BIM in FM are, this group may find it difficult to be firstly convinced and secondly able to identify exactly what they want from the model.
- Short timeframes: the short period allocated for design development was identified as challenging during the first six month of paralleling activities which is considered to have created rework in design documentation.
  This was also reflected in the documentation showing that design and construction activities overlapping prompted a clear need to create a special workflow. This helped the team deal with changes to the design that occurred after handover to sub-contractors so these changes would be communicated and captured by the construction models in a timely fashion. This was achieved by using a file exchange process that ensured that the fast tracked design programme would not affect model accuracy from sub-contractors.
- Inadequate quality assurance and bad habits: individuals having “bad habits” such as drawing in 2D instead of extracting from the model, staff taking “shortcuts” and not setting up elements properly or adding poor information were some of the challenges faced. It was also identified that some of these issues arose from lack of trust in the data contained in the model by certain parties as well as lack of understanding of proper procedures or of willingness to change. To address this challenge, data reconciliation tools and workflows were established in order to ensure all data from the schedules was also present in the model.
- Different data requirements for each phase: this was identified as a challenge when transitioning to operations; eliminating information from construction and design that will not be useful during operations. Additionally, creating interfaces between the construction data in

the BIM and the asset management system was also seen as a future challenge. This is reflected in the fact that if redundant parameters and data exist in the model, it will not be accepted for handover. To address this challenge the project team was identifying those parameters that were in the model and finalising a list of those that are to remain. For example, there are 242 parameters currently associated to doors. It was however proposed that only 99 are required for operations and maintenance. Therefore, 143 parameters need to be revised against the needs of the asset management system.

- Data security and access: it was mentioned that data security when using cloud computing was a source of concern that needed to be addressed. It was also mentioned that determining who has editing access to the model was a challenge which, in some cases, limited what certain disciplines could do directly.
- Compatibility: some of the information produced by suppliers and sub-contractors was not directly compatible with Revit. This created rework for consultants and suppliers who had to re-create the information in the formats required by their software.
- Different way of doing things: it was acknowledged that certain disciplines have had to become comfortable with producing more information at earlier phases of the project.
- Speed of change: it was highlighted that the speed at which new software is being developed as well as the sheer number of options presents a challenge for managers aiming to maximise BIM capabilities.
- Changes to brief: changes to brief after project start-up limited certain benefits such as lower cost and shorter project delivery time.
- Lack of standards: it was considered that there were no standards available that suited Australian procurement processes, which limited the "intelligence" of the model and ability to manipulate the data. This is seen especially as a problem for asset management where the workforce still needs to fully understand the implications of BIM for their systems and processes but there is a lack of readily available guides and standards for this purpose. It was however acknowledged that there is a national and international focus on developing standards by different countries and organisations including NATSPEC and buildingSMART.
- Contract: it was mentioned that the nature of the contract chosen limited the direct value realised by the client from using BIM 4D and 5D.

10. LESSONS LEARNED FOR MANAGERS

- Hardware limitations should be considered when determining the design team size.
- 4D modelling provides the most benefits when used for problem areas, unless the model can include form work and scaffolding.
- When working with many different teams in the development of BIM, sometimes simpler tools such as Microsoft Excel can be very useful for quality analysis and automatic fast identification of discrepancies in data sets.
- The importance of maintaining the same naming conventions by all consultants is paramount. Otherwise certain geometries might not be included in the clash detection test and the results would be incomplete, hindering the realisation of benefits from this tool. To make sure that this is not happening, simple audits selecting all search sets can be used by changing their colour set, quickly identifying those that are not being recognised due to incorrect names. Naming conventions may also adversely affect how certain parties utilise the model. For example, dimensions, material and similar costing information is essential for cost planners. To address this, the naming convention chosen should take into account the cost estimation software (e.g.

CostX). Family parameters should also be made consistent in order to reduce rework and confusion.

- Site administration through BIM should be more rigorously applied from the start of the project in order to obtain most benefits.
- “Human gates” (quality assurance systems that limit design changes register unless formally signed-off) can be useful in curbing “bad habits”.
- In order to maximise benefits from BIM, the following issues should be considered at the beginning of the project: data structure and standard formats (including object family classification), integrated libraries, BIM requirements for different life-cycle phases and ultimate goals, model governance and interoperability.
- Ensuring maximum information quality possible needs to be engrained in all processes.
- Small details can create a significant amount of rework if not addressed early in the project. For example, if the Project Units in Revit are set to whole numbers, each dimension will be rounded up which will increase the total cumulative value of the dimensions of each individual object. The unit symbol also needs to be set to none so quantity surveyors can input specific unit types during their quality assurance processes. Thus, if the project units are not set properly, the accuracy of cost and quantity calculations may decrease and benefits such as improved cost accounting and more accurate quantity take-offs may not be realised.

11. PROFILES

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

11.1. BENEFITS

The following sub-sections provide profiles of each benefit outlined in Section 5. These are based on all the data available from this case study. Each benefit is divided into design, construction and design, construction, expected during asset management, unrealised and future projects. Examples are also provided.

11.1.1. ASSET MANAGEMENT LABOUR UTILISATION SAVINGS

Expected during asset management – having an accurate as-built BIM model will reduce the need for re-walks and re-surveying during operation to verify elements of the asset. It is also expected that the model will provide easy and quick access to information such as manuals, maintenance schedules, and test data among other.

11.1.2. BETTER CHANGE MANAGEMENT

Design and construction – the use of BIM has allowed to track changes (and their reasons) throughout the project life-cycle. BIM has also been used to communicate changes, through for example videos. It also allows different parties to have access to these changes and carry out their own analysis, in turn reducing the likelihood of conflict by increasing transparency.

11.1.3. BETTER COST ACCOUNTING

Construction – the cost of FF&E elements can be more accurately calculated based on up-to-date information directly extracted from the model. BIM processes, schedules, quantities and rates of elements were used to create cost reports for the project by quantity surveying services. The model was also used initially at a level of detail equivalent to LOD200[9] to calculate a preliminary estimate of these services and to improve the accuracy of the overall cost plan. The use of tools such as BIMLink also allowed structural engineers without authoring abilities to input design and cost sensitive data relating to the concrete strengths and reinforcement rates for the superstructure. This information was then used for more accurate cost calculations and other analysis.

Expected during asset management – accountants and quantity surveyors will have access to more detailed and accurate information about equipment and other assets to calculate depreciation. It would be expected that if the model information is up-to-date and accurate it could be used to develop more accurate asset management budgets. Ideally, tools may be available that allow using information associated to plant and equipment to produce budgets that account for life-cycle cost.

11.1.4. BETTER DATA/INFORMATION CAPTURING

Construction and expected during asset management – the evolution of sections of the asset can be easily captured by taking pictures with hand-held devices which are automatically uploaded to the model. This will be especially useful for clients during commissioning and decommissioning.

11.1.5. BETTER ENVIRONMENTAL PERFORMANCE

Expected during asset management and other projects – more sustainable project outcomes related to better scenario analysis.

11.1.6. BETTER PROGRAMMING AND SCHEDULING

Construction – the model was also to be used for testing and review of the construction schedule. On-site logistics and task scheduling were improved through the use of BIM-enabled surveying tools such as Trimble and simulations that included construction equipment. For example, the construction team had concerns regarding site logistics associated to the reach and manoeuvring of booms within project boundaries. The booms were modelled and incorporated into the BIM. This allowed the team to visualise and schedule the use and location changes of this equipment required for the installation of the façade. This in turn reduced idle time of equipment and labour while increasing the accuracy of site logistics. There is also the potential for future construction tasks to include the use of real-time on-screen progress information. However, this has not been observed yet.

11.1.7. BETTER SCENARION ANALYSIS

[9] As defined in the contract documentation.

Design – the model was used as basis for a number of analysis including acoustic, fire safety, security coverage and structural changes to improve the final asset. This is enabled by having both spatial and analytical data associated to model elements and interoperability between software packages. The information extracted from the model was also used for sun and shadow simulations for certain patient areas and the roof garden at various times of the day and seasons.

11.1.8. BETTER SPACE MANAGEMENT

Construction – the model was to be used to resolve space coordination issues by using geo-references and shared coordinates associated to model elements as part of the coordination and authoring tools. This benefit was achieved through for example clash detection tools.

11.1.9. BETTER USE OF SUPPLY CHAIN KNOWLEDGE

Design and construction – stakeholders are more engaged in the design and construction process while having easier access to up-to-date accurate information about a number of processes. This provides better basis for feedback from a number stakeholders across the supply chain to improve constructability and final outcomes. For example input of engineering data was used as the focal point for resolving certain design and construction issues. It was reported that this would have not been achieved without the ability for personnel other than designers (such as quantity surveyors, structural engineers and construction programmers) to analyse model information and assign the correct piece of data to the engineering data field.

11.1.10. COMPETITIVE ADVANTAGE GAIN

Design – one of the consultants has gained a competitive advantage by providing BIM management expertise which provided access to new markets. Automating the model federation also reduced the resources required for this task making smaller projects more economically viable.

Construction – certain tasks such as set-up required less time and resources which can help provide more competitive prices and schedules.

Design and construction – parties have access to more cutting-edge technology than their competitors.

11.1.11. FASTER INFORMATION EXCHANGE

Design and construction – information is more easily shared and accessed. In this project, the consultants were able to create and send accurate schedule information within minutes from receiving the request. This information was used by the contractor for quality assurance and accountability regarding sub-contractor submissions.

11.1.12. HIGHER PROCESS AUTOMATION

Design and construction – previously time-consuming tasks such as clash detection and updating information across documents can be done *almost instantaneously* leading to lower resource investment (staff hours) for those tasks and easier data management. Additionally, information and changes are automatically propagated to other systems. For example, procurement of FF&E can be done directly from the model without the need for manual input. Any changes are automatically updated in these systems allowing procurement managers to react promptly.

Targeted clash detection was used during model reviews for penetration coordination of core service risers through predetermined views and clashes. This allowed the team to quickly identify where penetrations of core walls were not yet identified, designed or documented.

Future projects – information contained in the model may be able to be used in future projects through new pre-programed protocols to automatically calculate the impact of changes on specific areas and produce reports. It may also be possible to use information directly from the BIM towards prefabrication. This was not possible for the PCH due to lack of capabilities by local suppliers.

11.1.13. IMPROVED COMMUNICATION

Design – design elements and intent are more easily communicated through BIM-based visualisation tools. These virtual mock-ups allow walk-throughs with end-users and clients as well as fast and easy production of different views provide a more intuitive accelerated familiarisation process. This leads to more informed decision making and better outputs based on better feedback from different stakeholders. For example, end-users had access to accurate models of the rooms they would use when the hospital is completed and could "walk" the room through an avatar of their height and build (see Figure 3). This allowed demonstration of line of sight and movement patterns within the model for an area which was disputed based on a misunderstanding of the 2D drawings. This led to almost immediate sign-off of individual spaces by end-users.

The use of space can be better visualised and detailed. A situation was found around the location and size of slab penetration and set down. The team was able to create views during meetings which allowed isolating disciplines one at a time, and discuss and resolve issues individually. In another example, BIM models were used to produce first person viewpoints from the position of CCTV cameras. This allowed the client to have a better understanding of the scope of coverage that the cameras could provide based on their specifications. This exercise provided the client with more complete confidence about the CCTV camera layout required for sign-off.

The use of BIM therefore facilitates improved engagement of end-users and faster consultation, review and approval processes.

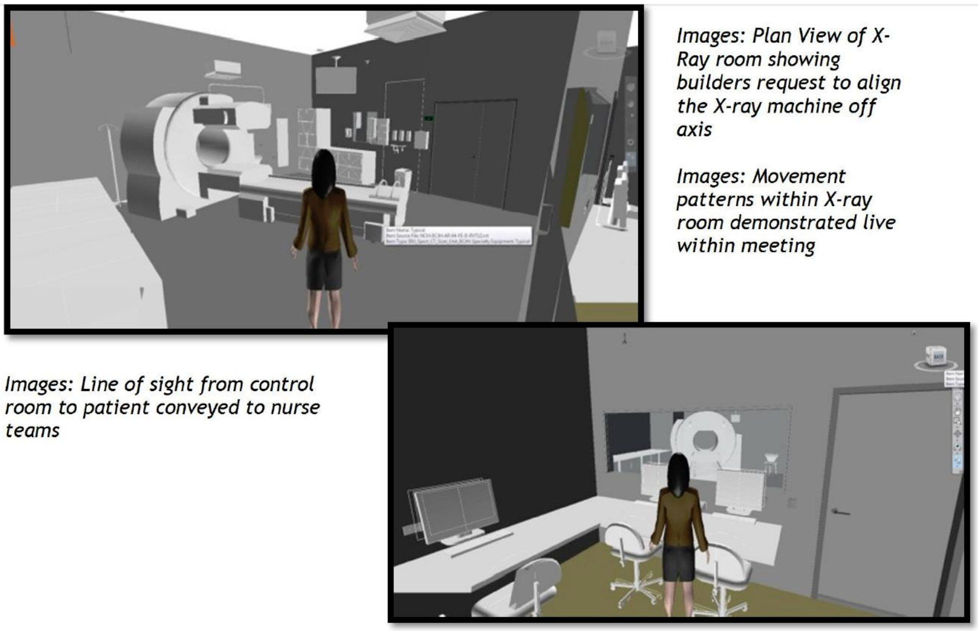

Figure 3 Avatar walk-through example

Construction – scoping documents are issued with model and schedule information to quickly and easily convey the tasks to be undertaken. For example, views and schedules from the model were used by project engineers to identify and quantify the types and number of doors within each specific work package. A colour-code was used for easy visualisation.

Design and construction – information is exchanged faster, is more accessible and all stakeholders use the same terminology. This allows faster understanding of issues and data, and less information lag and asymmetry of access. This in turn reduces the probability of misunderstandings, confusion and conflict. For example, a colour coded view of the model was used for clash detection between mechanical and electrical systems. This information was used during the review process and helped expedite decision making without major conflicts.

11.1.14. IMPROVED DATA AND INFORMATION MANAGEMENT

Construction – on-site crews can access information more easily through the use of hand-held devices. This information includes task status tracking which is made more visible through BIM project coordination and management tools.

Design and construction – an integrated database allows easy and quick access to information which is long-lasting and auditable. This is enabled by unique identifiers and structured data as well as common data and storage environments. The ability to clearly document and store changes to the design throughout the project life-cycle helps resolve claims and conflicts between disciplines.

Specific software packages used in this project have allowed interoperability between software packages allowing different stakeholders to use tools within their skill set without losing information transferability. Data flows are improved between disciplines and between project phases to provide a more complete asset register.

Importantly, all stakeholders have access to the same information avoiding parties to act on out-of-date information. In this project, this was seen as particularly beneficial for example for FF&E procurement where staff could use the same data for ordering, receiving and paying for goods. This also led to less time required to find and validated information. Samples for example are being labelled with unique identification numbers which can be tracked through BIM tools. This allows the team to have a record of all communications related to each sample in a single integrated system.

Expected during asset management – the model will contain all the information relevant to the operations and maintenance of the asset in a long-lasting, accessible and more integrated format. This is expected to enable operational personnel to track items for maintenance and repairs more accurately and effectively. This data-intense BIM for asset management model approach is also expected to serve as basis for better and more informed decision making during the operations phase.

Future projects – the potential exist for portfolio managers to integrate the BIM models from a number of assets and allow multi-asset management from a single platform. This may allow the client to track assets and carry out analysis that can increase overall efficiency across the portfolio. This would potentially also ensure a more standardised reporting system across projects and assets.

11.1.15. IMPROVED DOCUMENTATION QUALITY AND PROCESSES

Design and construction - documentation contains more complete information at earlier phases of the project. This is due to the ability to access information from different disciplines easily and identify poor or missing documentation through BIM systems before handover. Increased transparency leads to more collaboration and resolving issues sooner which in turn allows the design to be developed faster based on better informed decision making processes. This benefit is enabled by having different work packages within the model by scope and type. This allows: visualisation of scope, easy quality assurance of individual work packages, identification of differing work types within each work package, and the issuing of scoping documents that include models and schedules to quickly and easily convey the works to be undertaken.

11.1.16. IMPROVED EFFICIENCY

Design – drafting can be done anywhere in the world, this flexibility allows the selection of the most efficient design team regardless of geographical location. Additionally, the time required for design analysis was significantly reduced for certain tasks. For example, time required for acoustics and fire rating analysis of certain design features was reduced from several days to a couple of hours. The time required for clash detection was also reduced from 40 hours to 2 hours.

Design and construction – less time investment is needed in order to review datasheets, assessing contractor's claims against milestones and FF&E scheduling. This is enabled by better communication and faster access to up-to-date information which avoids confusion and conflict. BIM also allows easier changes and progress reviews through the input of information captured on specified dates and comparison with the live model. This was done by isolating and colour coding sections from different dates allowing easy visualisation of the progress and changes. This process dramatically reduced time traditionally taken for overlaying printed drawings and marking up changes.

11.1.17. IMPROVED PROJECT COORDINATION

Design – there is better coordination between design elements and documentation. Design staff is always working on the latest design version which is coordinated with other design professionals.

Construction – documentation used for field work is better coordinated. Construction tasks can be better coordinated as well by including site cranes, hoists and elevated work platforms (EWP), boom concrete pumps, presto platforms and other similar elements in the model. This allows the site team to understand the specific reach of these elements and coordinate site logistics. For example, site logistic BIM planning tools are being used for boom pump pour planning that takes into account equipment reach radius and site logistic clash detection. Another example is the use of BIM for targeted coordination of mechanical riser ducts which were found to be larger than originally thought due to system performance requirements.

Additionally, documents can be easily created and used as required to convey the works to be carried out by different disciplines. The model was also to be used for analysis and resolution of spatial coordination issues through geo-referenced models based on shared coordinate systems and accurate discrete model components.

Design and construction – scope and objectives are better aligned across stakeholders. This project aimed to use BIM to eliminate installation and construction coordination issues through *a coordinated, integrated and controlled project delivery team* achieved by weekly coordination meetings and a collegiate approach to the work and modelling tasks. Project details are coordinated at all times and facilitated by better change management and improved communication through better visualisation.

11.1.18. IMPROVED SAFETY

Construction and expected during asset management – the use of BIM to test alternative construction methodologies allowed the use of prefabricated sections of the mechanical riser which improved the safety of the installation. The model reviews also prompted changes to certain features of the design that reduced work at heights as well as made easier future service reticulation in the ceiling space, all of which improved staff safety during construction works and future operations.

11.1.19. IMPROVED OUTPUT QUALITY

Design – virtual mock-up of rooms including walls, ceilings, windows, and major FF&E was used during end-user reviews to improve the final design. This allowed better end-user engagement and room designs which are adequate for their intended use. The use of BIM also allowed the production of high quality detailed design documentation within a compressed timetable.

Design, construction and expected during asset management – BIM was used to optimise the design and final asset based on operational requirements. For example, the model was used to simulate the use of EWPs for façade maintenance and ensure it could be cleaned. The model was also used to redesign structural steel elements to ensure constructability of the risers and to review and test geometrically different construction methodologies. This led to the decision of constructing the mechanical riser in prefabricated sections within steel cages that could be delivered to site and lowered into position. This change additionally produced time savings and improved safety.

11.1.20. LOWER COST

Design – the use of automated clash detection reduced labour intensive man hours of the design team that would normally be required for overlaying and marking drawings. It was estimated that a specific task related to clash detection normally requiring 40 hours of work was reduced to a total of 2 hours thanks to the use of BIM.

Construction – less resources are needed for site set-up and lower risk can help reduce the cost of the project for individual stakeholders such as clients and sub-contractors. Coordination of views and better understanding of the design requirements thanks to BIM also produced cost savings. Using BIM for analysing shaft walls and stairs allowed the project to save approximately \$80/m^2.

Design and construction – there are cost savings provided by less rework. The project also experienced cost savings in printing paper copies of drawings.

Unrealised – Lower overall cost of delivery may have been achieved under different circumstances. This was hindered by a number of brief changes. However, it was acknowledged that the use of BIM probably helped avoid larger cost overruns.

11.1.21. LESS REWORK

Construction – planning and coordination of on-site tasks by different disciplines as well as for procurement of parts and equipment is made more effective through the use of BIM project coordination tools and access to more accurate up-to-date information. This leads to less need for re-doing these tasks.

11.1.22. MORE ACCURATE QUANTITY TAKE-OFF

Construction – information associated to design elements is more accurate and available directly in the model. This allows more accurate quantity take-off calculations when the information is attached to the element. The team was able to readily identify a discrepancy between supplier's costing and that calculated based on the model producing savings in materials. The project team was also able to create a custom DWFx[10] export protocol from Revit for interrogation of CostX[11] files. This protocol was used by

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[10] DWFx is a file extension format used by software providers such as Autodesk to save 2D or 3D drawings using XML Paper Specifications (XPS).

[11] Description available in the Appendix

the contractor and sub-contractors to prepare quantities, with exceptionally close results. The model was also used for the cost plan, providing a more accurate bill of quantities associated to concrete, structural steel, reinforcement, service points, windows and doors, among other elements.

11.1.23. REDUCED LEAD TIMES

Design – the use of BIM has allowed faster approval of drawings with the client using the model for an estimate of up to 90% of approvals[12].

Design and construction – latency between asking a question and receiving a response is reduced leading to less wasted time. This is often facilitated through BIM model group reviews and also improves the latency associated to feedback from specific stakeholders. For example, a situation arose that a sub-contractor was required to mark drawings to resolve the location of clashes of their service. Instead of waiting several days to receive this information, the issue was resolved through a model review meeting with the sub-contractor and input directly into the BIM. Additionally, information acquired through a BIM analysis to identify areas of conflict between services and partition was easily presented to stakeholders for discussion and helped expedite the decision making process.

11.1.24. REDUCED PROJECT EXECUTION TIME

Design – the use of integrated systems, fast information exchange and easily accessible data allowed different design stages to be carried out in parallel.

Construction – construction tasks can be carried out faster due to site crews having access to more accurate information, leading to fewer clashes and easier and more accurate set-out by sub-contractors. This is enabled by the use of BIM-compatible on-site surveying tools.

11.1.25. REDUCED RISK

Design and construction – BIM provides a better understanding of project risks and provides the tools to discover issues at earlier phases of the project, this allows a clear strategy to be devised to eliminate or reduce risks. Supply chain stakeholders are also more engaged in this process, making the risk assessment more holistic and better informed. Improved communication also provides the opportunity for better alignment around the project objectives and scope of works, reducing risks associated to misunderstanding and future conflict.

11.1.26. SHORTER DELIVERY TIME

Unrealised – under different circumstances BIM has helped achieve shorter delivery times in projects experienced by some of the interviewees. However, in the case of the PCH there have been a number of

[12] This was an estimate made by an interviewee, evidence was not found in the documentation reviewed to support this claim. However, PCH representatives clarified that Room Data Sheets and Room Layout Sheets are now reviewed and approved by the client staff mostly through the model. Other design approvals were estimated at 50% through BIM.

brief changes which have hinder the realisation of this benefit with respect to the project expected completion date. Nevertheless, it was acknowledged that the use of BIM provided benefits for the PCH of shorter delivery times with respect to the completion date that would have been expected under traditional methods.

11.1.27. OTHER

Design and construction – improved learning culture and forcing people into changing design thinking.

Future projects – it is expected that the use of BIM in future projects and asset management will change how future capital projects are designed, constructed, handed over, operated and maintained.

11.2. ENABLERS

The following subsections provide profiles of each enabling tool outlined in Section 6. These are based on all the data available for this case study. Examples are also provided.

11.2.1.3D VISUALISATION AND ANIMATION

By creating and placing avatars in the model, clients who struggled to understand the design in 2D received instant understanding of how a design or room layout was to function. 3D visualisation of virtual mock-ups were used for virtual walk-throughs with the client and end-users in order to improve communication, ensure suitability of final design and expedite the decision making process. Virtual mock-up for example was used to demonstrate the coverage range of CCTV cameras and obtain approval on their location. Navigation of the model also allowed the identification of areas of conflict between services and partitions. Animations based on the model were also used to demonstrate construction sequences.

11.2.2.ASSET MANAGEMENT SYSTEM INTERFACE

The team was creating an interface between the BIM platform and the asset management platform (Agility). This should allow better data and information management and better cost accounting during the operational phase of the asset's life-cycle.

11.2.3.AUTOMATED CLASH DETECTION

Targeted clash detection tools allowed identifying particular building elements against particular services to provide a greater level of design coordination and were conveyed in a high level group clash format which allowed easier resolution. The educated clash detection style used in this project allowed the reduction of time required for this task from 40 hours to 2 hours. Additionally, the hierarchal approach to clash depiction enabled the project team to efficiently identify which clashing elements were to be moved and which parties had linked responsibilities. One of the consultants also developed and ran a series of clash detection routines in the federated model.

11.2.4. BIM-ENABLED SURVEYING SOFTWARE

Trimble S6 Total Station was used to carry out on-site surveys based directly on BIM 3D model. This allowed faster project delivery and less rework through faster and more accurate site set-up.

11.2.5. CLOUD STORAGE AND INTEGRATED DATA MANAGEMENT SYSTEMS

Some of the members of the project team were working off-site which led to the decision of using tools that would allow those working remotely to continue working collaboratively and have access to information. A cloud-based server allows all parties to have access to up-to-date information at any time.

Panzura[13] was being used as the cloud storage system for working on the model remotely and Buzzsaw[14] as the cloud-based file transfer system to send and receive all model documentation. This type of tool commonly helps increase efficiencies by allowing modellers to be located off-site, including other countries in different time-zones. This system also allows tracking which staff members have logged in, when and for how long as well as clearly identifying changes made by that person. This produces an auditable report and improves change management.

11.2.6. CODE-CHECKING AND VALIDATION

BIM360 was used for this purpose to avoid having more differing systems. It allowed carrying out quick audits throughout the different stages of construction.

11.2.7. CO-LOCATION

Refers to having the project team composed by client, contractor and designer in the same location. This was seen to enable improved communication and fostering collaboration. It was also observed to facilitate faster access to data by enabling the use of a single server and requiring less hardware, thus also reducing cost of implementing BIM.

11.2.8. BIM MANAGEMENT AND COLLABORATION SOFTWARE

BIM360 was used to associate photographs to model objects and writing field-reports more efficiently through direct input into the model. The resolution of these reports could also be tracked through this software and it provides checklists for a number of tasks. The client was also planning to use this software for commissioning. This tool provided better communication and improved data management benefits, as well as less conflict and improved efficiency.

[13] Product description can be found in the Appendix.
[14] Product description can be found in the Appendix.

BIM360 Field was being implemented to provide the ability to use mobile technology and other hand-held devices for field management for 2D and 3D environments. Staff could use it to produce all information needed before finishing a construction task (e.g. closing a wall) before the engineer signs off. This is all synched with the model.

BIM360 glue was planned to be used to allow immersion technology and access to the model through hand-held devices. Together with the use of Radio Frequency Identification (RFIDs) in every room, this tool was expected to allow the team to use their hand-held devices to recall all information related to the room they were in by scanning the RFID, then populate any reports or changes directly into the model.

11.2.9. DATA INTEGRITY AND DATA RICH INTEGRATED MODELS

Accurate and reliable data was seen as a requirement for all BIM benefits. The project documents especially emphasised that having a complete and accurate model with all appropriate information for maintenance and operations is a key requirement for the project.

Data-rich models also helped facilitate cost accounting and the use of most of the enabling tools used in this project. Having all this information in a single model provided a single source of truth which was accessible to all parties, improving efficiency, reducing rework, and improving information management and communication. This project used a federated model, frequent coordination review meetings and a number of tools such as Buzzsaw and BIMlink[15] to make this possible.

For handover, all parties were required to provide the model with a specific set of shared parameters that would allow the BIM manager to filter all information which was no longer required during operations and maintenance and ensure there was no redundant geometry left.

11.2.10. DATA RECONCILIATION TOOLS

BIMLink served this purpose of allowing users to pull data from Revit files into Microsoft Excel and vice versa. This capability was used for easy document quality control and to provide a simpler tool for non-BIM authoring staff to input data into the model.

BIMLink was for example used to complete the concrete grades and reinforcement rates for the superstructure. This allowed structural engineers to input the design and cost sensitive data relating to the concrete strengths and reinforcement rates for the superstructure. Information for pricing such as cost codes, steel sections tonnages, and work packages was also used to pull quantities for costing and analysis purposes.

The team used a large set of parameters which can be exported through BIMLink into Excel and back to the model. This has allowed the model to be a centralised single point of truth for example for all door related information.

[15] Product description can be found in the Appendix.

11.2.11. FREQUENT PROJECT TEAM MEETINGS

Regular meetings provided a space to resolve issues quickly using the model, without the need for all parties to have modelling skills. This was thought to have reduced conflict and misunderstandings.

11.2.12. HEALTH AND SAFETY SIMULATIONS

Although it has not been used across the project, it was trialled on the request of one foreman who used it for training and briefing sub-contractors about safety issues.

11.2.13. INTEGRATED PROGRAM MANAGEMENT TOOL

dRofus was being used for scheduling FF&E requirements and it was used for quality assurance. However it was the opinion of one interviewee that the full capabilities were not been used due to lack of access clearance for certain roles.

11.2.14. ISSUES AND PROJECT TRACKING SOFTWARE

JIRA was used for tracking any issues related to elements of the asset during design and construction. This tool enabled less rework, better project coordination and improved data and information management.

11.2.15. PROJECT LOGISTICS TOOLS (4D)

This tool provided access to architectural and work-site information, including traffic, hoist equipment and staff, helping improve site project coordination and programming/scheduling. It was particularly useful for “problem zones” which had been identified by field teams and then modelled in 4D. This allowed better programming and communication with sub-contractors and foremen as well as improved site planning.

The project team developed a BIM workflow to track the progress of the construction of façade against the planned schedule using colour codes (Figure 4). This effort aimed to increase efficiencies gained from BIM. To achieve this, the planning team attended a series of small workshops to refine the workflow and learn how to use it. It was also intended to use colour coding to visually identify which trades were involved in each area of the project. However, it is not clear whether this was achieved.

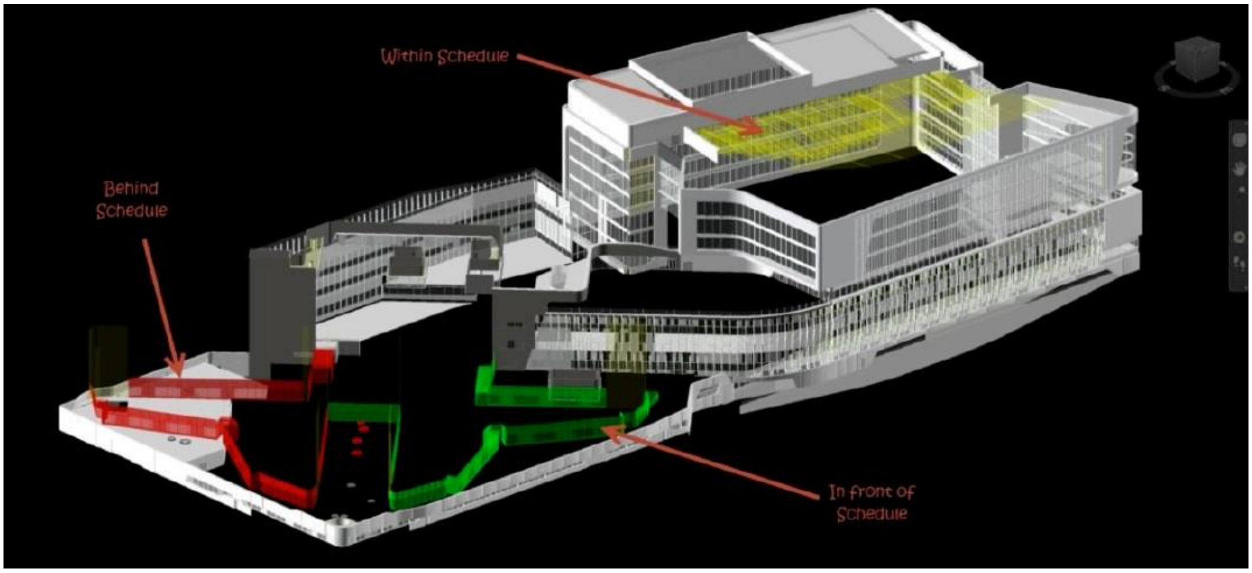

Figure 4 Example of graphical 4D representation

11.2.16. PROJECT REVIEW SOFTWARE

Navisworks from Autodesk was used as the project review software solution. This tool allowed better coordination of documents on-site, less conflict and, together with regular team meetings, better communication. This software type allowed stakeholders without modelling skills to have access to the model and manipulate it in order to obtain information.

11.2.17. RADIO FREQUENCY AND UNIQUE IDENTIFICATION

RFIDs were being used to track any maintainable asset[16], providing fast access to all information contained in the model that is related to that asset. Using unique IDs the project has been able to use a tracking system that links to a database to track the progress of physical objects, typically through the use of bar coding systems. Having unique IDs associated to the different elements (including equipment and fixtures) has provided more visibility into the data and changes history of the element, improving data and change management.

Activities during construction were also assigned unique IDs to facilitate the use of 4D BIM.

11.2.18. SMART HAND-HELD DEVICES

The use of tablets allowed faster and easier access to information as well as better data capturing through photogrammetry (i.e. taking pictures which are directly uploaded to the model and associated to specific elements).

[16] It was clarified that RFIDs were used at the time of this case study only for mechanical, electrical and plumbing elements but were planned to be used for FF&E in the near future.

11.2.19. SOLAR, WIND, ACOUSTIC AND THERMAL ANALYSES

The team was able to export data from the model into solar, wind and thermal analysis software tools to determine where the shading and open garden space within the building should be according to the orientation of the building and façades. These analyses also included internal lighting analysis in order to allow the use of natural light, and noise modelling to reduce noise from the external environment. Acoustic analysis based on the model were also carried out. In this case it was found that the use of BIM reduced the time required for this exercise from several days to a couple of hours.

11.2.20. STRUCTURED DATA

Having well-structured data in a single database made information more accessible and allowed filtering and data mining. The project team developed a large set of shared parameters that were used throughout the project life-cycle in order to have consistency across the database which will later be used for asset management.

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13. APPENDIX: SOFTWARE SOLUTION SHORT DESCRIPTION

This section provides short descriptions of the software solutions mentioned in this report.

13.1.1. AGILITY

Agility is a Computerised Maintenance Management Software (CMMS). It is a simple browser based solution that provides features for managing *breakdown and preventive maintenance work orders and the associated spare parts and resources for small maintenance departments through to multi-site corporate businesses.* It provides *up-to-the-minute* information about assets, work orders and planned schedules (SoftSols Group, 2015).

13.1.2. BIM360

BIM360 is a collaborative construction management software use for remote access to project data throughout the building construction life-cycle. BIM360 Glue is a cloud-based service for BIM management and collaboration used for connecting project teams and streamlining Building Information Management (BIM) project workflows. BIM360 Field is a cloud-based service for field management that uses a mobile app for on-site for collaboration and reporting (Autodesk, 2015a).

13.1.3. BIMLINK

Ideate BIMLink allows extracting data from an Autodesk Revit files into Microsoft Excel and vice versa. The tool was developed specifically for the Revit community to complement Revit Architecture, Revit MEP and Revit Structure (Ideate Software, 2015).

13.1.4. BUZZSAW

Buzzsaw is a *data management software as a service (SaaS) that helps enable Building Information Modelling (BIM) workflows. It includes tools for documentation, modelling and data management and it's* [sic] *integrated with the Autodesk portfolio of design and data management solutions* (Buzzsaw, 2015).

13.1.5. COSTX

CostX® is a software designed to *produce quickly and accurately take off quantities from 2D drawings and generate automatic quantities from 3D models/BIM.* The software allows preparing estimates, bills of quantities and tenders (Exactal, 2015).

13.1.6. DROFUS

dRofus is a software for integrated program management that supports: planning and administration of areas, rooms and departments/functions; room datasheets; registration and monitoring of the requirements for each room; FF&E planning, cost control and procurement of FF&E; check and visualisation of designed model through IFC; and bi-directional plug-in's for Revit and ArchiCAD (dRofus, 2015).

13.1.7. NAVISWORKS

Navisworks is a project review software that aims to enable *architecture, engineering and construction professionals to holistically review integrated models and data with stakeholders to gain better control over project outcomes*. *Integration, analysis and communication tools help teams co-ordinate disciplines, resolve conflicts and plan projects before construction or renovation begins* (Autodesk, 2015b).

13.1.8. JIRA

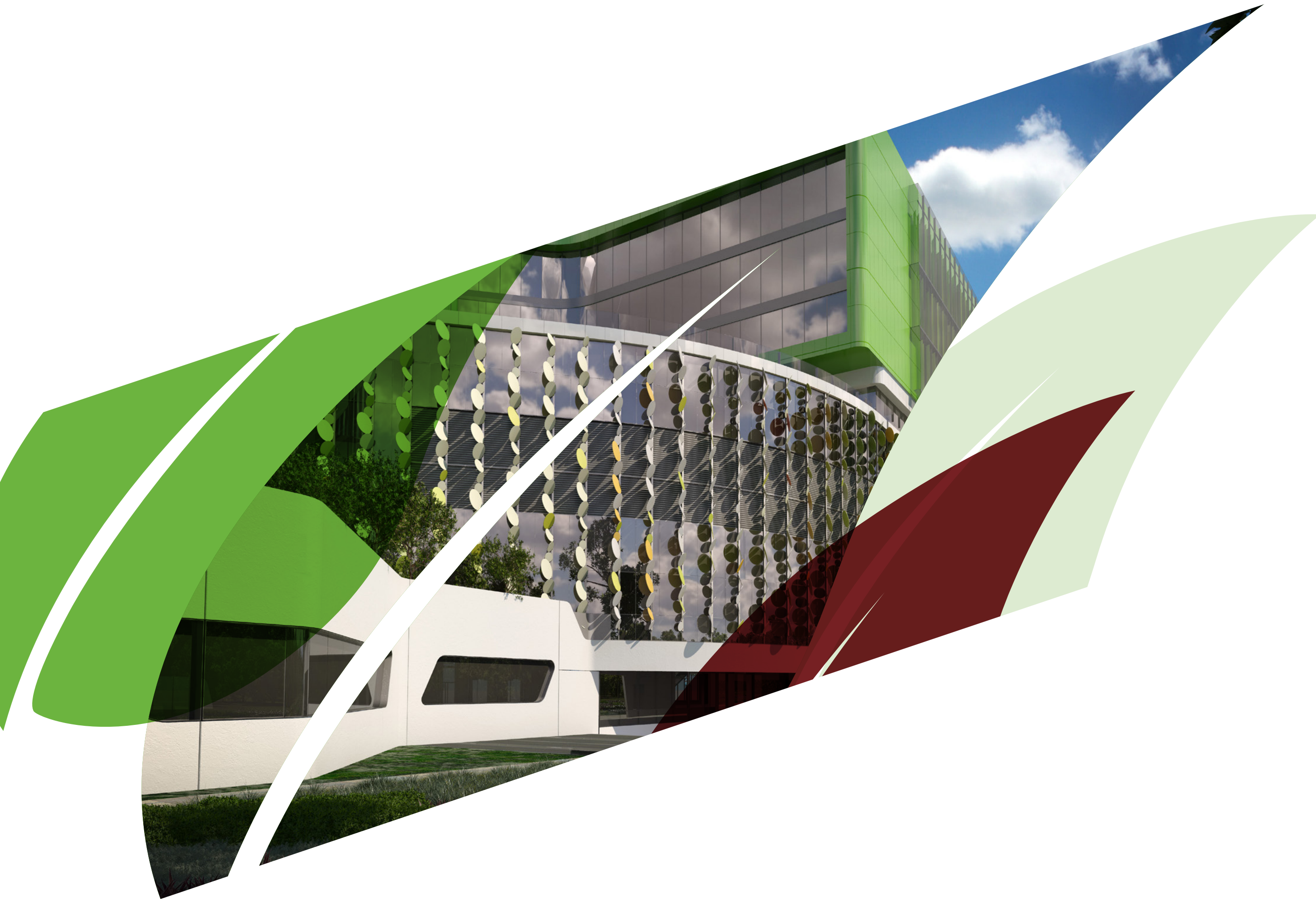
JIRA is an issue and project tracking software that allows teams *to capture and organize issues, assign work, and follow team activity*. The software has a mobile interface and allows to monitor activity streams as well as sharing information (Atlassian, 2015).

13.1.9. PANZURA

Panzura is a cloud storage system that provides *centralised storage to reduce local provisioning and management. This solution (plus cloud) eliminates the 'file open' problem and provides a global file system with a common view of all files across all locations, at all times, accessible from anywhere. In addition, the solution enables enterprise-class data services including consolidation, archiving, access, security, and a highly improved global user experience* (Panzura, 2015).

13.1.10. TRIMBLE

Trimble is a provider of advanced location-based solutions that aim to maximise productivity and enhance profitability. It integrates *GPS, laser, optical and inertial technologies with application software, wireless communications, and services to provide complete commercial solutions. Trimble serves a variety of industries including agriculture, engineering and construction, transportation and wireless communications infrastructure* (Trimble, 2015).



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