SYDNEY OPERA HOUSE

CASE STUDY REPORT

Sustainable Built Environment National Research Centre

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EXECUTIVE SUMMARY

The present report summarises the findings of the Sydney Opera House (SOH) Case Study carried out as part of SBEnrc Project 2.34 *Driving Whole-of-life Efficiencies through BIM and Procurement*. This report is informed by outcomes from interviews and document analysis as they relate to the development and implementation of the Building Information Modelling (BIM) for asset management interface at the SOH.

The SOH is an iconic Australian building with a long-standing history of innovative information management. This history starts with a challenging design and construction process which prompted what could be the first field-to-finish system for surveyors in Australia creating great efficiency gains, and now continues with the implementation of what is expected to be a fully integrated BIM asset management system.

The SOH BIM journey started in 2004 with the Exemplar Project carried out by the Cooperative for Research Centre (CRC) for Construction Innovation which tested a partial digital facilities management model and made a number of recommendations in 2007 based on collaborative research with the SOH. Since then, BIM practices have been used for construction works and their information management team has endeavoured in completing the BIM REVIT /Architectural model.

The SOH expects to achieve significant advantages from implementing BIM. Specific drivers identified were:

- Having a single source of information
- Information management issues related to the complexity of the asset
- Improving safety
- Addressing performing art requirements
- Sustainability goals
- Heritage listing status.

During the past 10 years, the SOH has faced the following challenges in the development of their BIM for asset management system:

- Software limitations/inadequacy
- Limited funds
- Data availability
- Finding the right answer
- Resistance to change
- Public asset government requirements
- Australia's geographic isolation
- Uniqueness of the SOH.

Success factors identified for the development of a BIM for asset management strategy:

- Inspiration and corporate culture

- External collaboration
- Client involvement
- Management vision.

The SOH has taken an informed and involved client approach to the development of their BIM guidelines and requirements. They have carried out extensive research into international and national practices, significant stakeholder engagement and collaboration as well as maintaining close ties to industry and research groups.

The SOH will aim to address the following expected challenges during the BIM solution rollout:

- Required skills and training
- Ensuring acceptance by end-users
- Integrating the different databases.

Future research will aim to understand specific benefits achieved from the implementation of the BIM interface for asset management systems.

1. ABOUT THIS REPORT

This report summarises the findings of the Sydney Opera House (SOH) Case Study carried out as part of SBEnrc Project 2.34 *Driving Whole-of-life Efficiencies through BIM and Procurement*. The case study draws from: (i) an interview series with SOH staff at three levels of decision making (information management, strategy and section director); (ii) documents analysis of key documentation provided by SOH representatives and interviewees; and (iii) information provided by other sources previously involved with the SOH.

2. ABOUT THE CASE STUDY

In general, this research seeks to answer the following questions:

(i) What frameworks and benchmarks exist nationally and internationally that could be applied to the evaluation of whole-of-life benefits gained from implementing Building Information Modelling (BIM) during procurement and asset management?
(ii) 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 sustainability factors throughout the life-cycle of assets?
(iii) How do existing procurement guidelines align with the defined KPIs and success criteria?
(iv) 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 gain insight into the uptake of BIM in complex projects during the asset management stage. The interviews have been divided into two parts. Part I included three interviews carried out on 06 February 2015 and aimed to understand “the journey so far”, drivers, success factors and challenges as well as the expected role of BIM in the new system. Part II is to be carried out in July 2015 including 6-8 interviews after the BIM for asset management interface had been rolled out. However, this section of the case study has now been postponed to be carried out as part of a new SBEnrc research project 2.46 *Whole-of-life Value of Constructed Assets through Digital Technologies*. The interviewees of Part I represented the client and are involved at different levels of decision making that pertain to the uptake, development and implementation of the new system.

Prior to the interviews, the research team received several documents that were considered important background for developing the interview questions and this report. These documents included contract guidelines, presentations, technical specifications and model management plan.

This research was carried out under a confidentiality agreement with the Sydney Opera House Trust and therefore the findings presented in this report are anonymised and have also been reviewed and approved for distribution to the Project Steering Group by a designated representative of the SOH.

Additional supporting documentation was provided by SOH representatives and interviewees. These documents were analysed and coded into emerging topics following a similar methodology to the interviews analysis. Relevant information was then compared to the interviews findings and included in the present report. The source of the documentation and parties mentioned has also been anonymised to protect potentially sensitive information, with the exception of documents which were already publicly available.

The document analysis aimed to find support for claims made during the interviews as well as expand the area of research. This report also includes information that although it does not relate directly to the questions used for the interview, it 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 Sydney Opera House 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.

4. ABOUT THE SYDNEY OPERA HOUSE

The Sydney Opera House (SOH) is an iconic Australian building of late modern architecture (Figure 1). Its history starts in 1956 when the NSW Government called an open-ended international design competition based on broad specifications without design parameters or cost limit. The winning design was created by Jørn Utzon who *gave Australia a challenging, graceful piece of urban sculpture in patterned tiles, glistening in the sunlight and invitingly aglow at night.* Since the start, *design and construction were closely intertwined* characterised by *an exceptional collaborative and innovative environment* (Sydney Opera House, 2015).

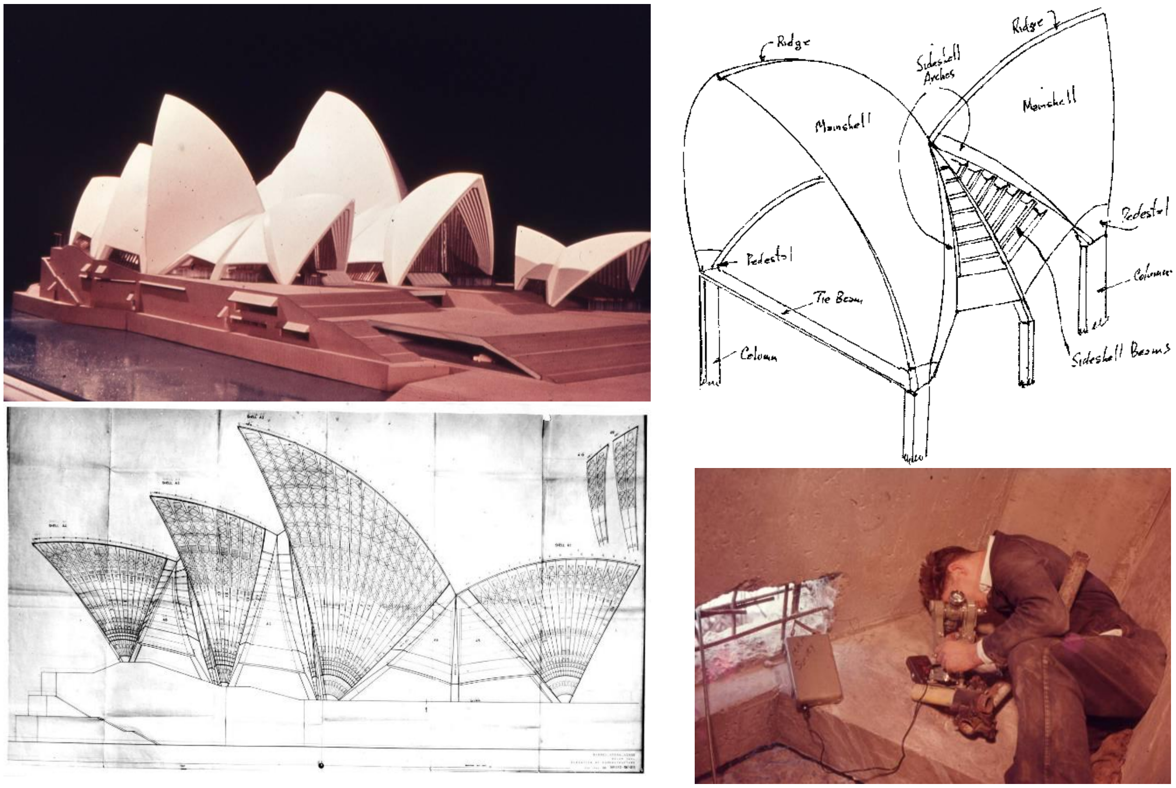

Figure 1 Sydney Opera House original model and drawings showing element information. Bottom right: Stations inside the arch were used when jacking the side shell arches to correct errors due to the compression of the formwork. The instrument is bolted to the shear pin linking the segment to the concrete below (Elfick, 2010).

Nowadays, it has been estimated that Sydney Opera House is worth AUD4.6 billion and contributes AUD775 million annually to the Australian economy (Deloitte, 2013). In 2014, the Sydney Opera House generated almost AUD100 million directly from sales, services and sponsorship, and spent AUD32.3 million on building maintenance (Sydney Opera House, 2014c).

4.1. BIM IN THE SYDNEY OPERA HOUSE

It's been a long, long path… from the BIM and FM as a business enabler, turning the dream into reality has been probably more difficult and taken longer than we would have thought.

SOH interviewee (2015)

The roof of the SOH is made by 1600 segments each weighing an average of 10 tons and the outside of the roof is clad with 5,400 precast tile panels. The highest point of the roof is 67 meters above sea level and the whole building has 10,000 tile bolts which had to be surveyed to a *guaranteed accuracy of ± 3mm so that the fixing brackets could be pre-set before each tile lid was lifted* (Elfick, 2010).

During construction it was found that the calculation work to process field data and generate reports would limit the response time of the project team at critical stages of the project. The usual time necessary to calculate a typical rib deformation was over a week. The requirement however was to provide results within the hour which led the team in 1965 to develop a computer program written in Fortran2 which automatically generated the necessary reports from the field observations. The surveyors would send their field reports by taxi to the location where the program was stored in a deck of punch cards which was loaded to a computer and the output was a series of written reports (Figure 2) which were then sent back by taxi to the construction site. This *was probably the first "field to finish" system for surveyors and it dramatically improved the response time as well as eliminating calculation errors* (Elfick, 2010).

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SYDNEY OPERA HOUSE - PHASE 2 SURVEY INFORMATION DATE. 000 000 PA

MAIN SHELL COMPUTATIONS

CODE NO	X CO-ORD	Y CO-ORD	Z CO-ORD	HORIZONTAL DIST STN TO POINT	OFFSET TO PLANE	RADIAL DISTANCE	ARC LENGTH
S/A/ 2/E/14/4/ 5	-73.019	59.789	130.394	72/ 75.137 35/ 95.447	0.472	246.122	96.473
S/A/ 2/E/14/4/ 3	-68.649	69.544	102.351	72/ 69.665 35/ 84.761	0.487	246.109	66.458
S/A/ 3/W/ 4/7/ 4	-136.969	-25.252	148.581	3/ 38.698	0.529	252.333	126.477
S/A/ 3/W/ 4/6/ 4	-135.444	-35.928	138.169	3/ 30.911	-2.918	245.999	111.483
S/A/ 3/W/ 4/5/ 4	-134.126	-45.995	127.132	3/ 25.760	0.517	246.015	96.485
S/A/ 3/W/ 4/4/ 4	-133.068	-55.395	115.485	3/ 24.194	0.504	246.004	81.479
S/A/ 3/W/ 4/7/ 3	-130.658	-23.697	147.660	3/ 35.658	7.090	252.332	126.478
S/A/ 3/W/ 4/6/ 3	-129.774	-34.536	137.347	3/ 27.127	2.978	246.011	111.488
S/A/ 3/W/ 4/5/ 3	-129.267	-44.793	126.407	3/ 21.450	5.572	246.006	96.482
S/A/ 3/W/ 4/4/ 1	-131.319	-79.785	76.596	4/ 11.610	0.476	246.017	35.478
S/A/ 3/W/ 4/3/ 1	-130.037	-79.464	76.402	4/ 10.382	-0.441	246.010	35.476

Figure 2 Computer Report - Layout was point code followed by XYZ position and then dimensions from the reference frame of that part of the structure (Elfick, 2010)

The construction program spanned over 15 years and the executed drawings and operational manuals provided at the end of construction were incomplete and unreliable as to their accuracy. This meant that in year 2000 the SOH had all the concept designs but lacked many of the as-built drawings, and two rooms stacked *floor to ceiling with plans and microfilms and copies of books and everything else* as the information database. At the time, individuals had started to amass documents related to their roles and, as they left the organisation, this information was often lost. This led the SOH to develop an information and documentation policy that required all employees to deliver all their documentation to a central information office. Here the documents were manually compared to those in record to avoid duplication of information and ensure version controls.

The SOH also had the Sydney Opera House Technical Documents Database (TDOC database) established in the mid 1990's to collate information about the engineering elements of the building. *It was also used to index a large set of microfilmed engineering drawings, covering the building's engineering disciplines* (Sydney Opera House, 2014b).

The SOH has been developing its BIM strategy since 2004 through their Building Development & Maintenance (BDM) Portfolio. *A structured system of Building Information databases and Building Management Control Systems (BMCS) provide the Facility Management (FM) tools for the day to day operation of the building and site* (Sydney Opera House, 2011). The idea of using BIM for FM originated from a presentation by Professor Keith Hampson at a Facilities Management Association of Australia conference that SOH Director Paul Akhurst attended. At this time, the SOH was already using 3D models for structural and other analyses in projects such as the Opera Theatre upgrade feasibility studies in 2003. The building also had developed internal processes that included a reference and coordination system. This system is based on each space having a reference area name and a unique space number related to a file system that contains a master set of documents of that room in a centralised location.

In 2004, the SOH started a collaborative research project with the CRC for Construction Innovation to research FM practices and demonstrate FM as a business enabler. This project combined three research streams related to digital modelling, services procurement and benchmarking (Kivits & Furneaux, 2013). At the end of this project in 2007, the CRC for Construction Innovation proposed that the Sydney Opera House should develop a BIM model. This system was to be *capable of integrating information from disparate software systems and hard copy, and combining this with a spatial 3D computer-aided design (CAD)/geographic information system (GIS) platform*. The objective was that the SOH would be able to mine data to improve the efficiency and effectiveness of their FM strategy as it related to their Total Asset Management (TAM) Plan and Strategic Asset Maintenance (SAM) Plan (CRC for Construction Innovation, 2007).

The CRC for Construction Innovation proposal included a BIM for FM framework supported by an open data exchange standard across multiple applications, use of data mining as an information gathering tool and integrated strategic elements. It also included the use of performance benchmarking to develop effective Key Performance Indicators (KPIs) for an integrated performance hierarchy assessment model. Some of the suggestions were: condition assessment (building structure and services, public spaces, internal fittings and finishes); energy management (rate of consumption and management); accessibility (security and information for visitors); and contractor's performance (quality of service, safety, timeliness and compliance) (CRC for Construction Innovation, 2007).

This research concluded that *tests with partial digital FM model data demonstrated that the creation of a complete Sydney Opera House digital FM model is realistic, but subject to resolution of compliance and detailed functional support by participating software applications* (CRC for Construction Innovation, 2007).

Following this work, the SOH team developed a set of BIM for FM objectives divided into four categories:

(i) Digital Modelling
(ii) Service Oriented Architecture
(iii) Enterprise Framework
(iv) Integrated Digital Model

Section 6.1 provides a detailed list of the objectives under each category and information about how they had been addressed as of 2014.

In 2009, the design work undertaken on the Vehicle Access and Pedestrian Safety (VAPS) project which contains roadway and tunnelling elements provided the SOH with an opportunity to test the use of a fully integrated BIM approach to construction. All the outputs of this project were required in formats that were highly interoperable in preparation for the implementation of a BIM asset management system in the near future.

In 2011, SOH issued their BIM Guidelines to assist organisations working on various building projects (including VAPS) who would prepare engineering documentation files for them upon completion of their contractual obligations. This effort was driven by the belief that *to use BIM effectively… and for the benefits of its use to be realised, the quality of communication between the different participants in the construction process needs to be improved. If the information required is available when it is needed, and the quality of that information is appropriate, then the construction process can be improved… For this to happen, there must be a common understanding of building processes and of the information that is needed for and that results from their execution* (Linning, 2011).

In this guide, SOH established their general BIM objective as: *to build up an accurate, reliable, and relevant integrated building model of the Sydney Opera House complex to support operational management, building and service system alterations and additions and asset and maintenance management… This is proposed to be achieved by progressive incremental development of a master model, in accordance with operational, logistic and financial constraints* (Linning, 2011)

In 2011, the SOH also issued the BIM Guidelines for Construction Phases as an adaption of the U.S. Department of Veteran Affairs (VA) and NATSPEC BIM Guidelines, *with an emphasis on construction and final deliverables* (Sydney Opera House, 2011). In 2012, the Scottish Ten[1] used laser-mapping technology to capture a point cloud map of the external structure, the main auditorium and some sections at the back of the SOH. This meant taking over 950 laser scans and *56,000 digital photos to produce the geospatially accurate point cloud* (Figure 3) (Linning, 2014a).

[1] *The Scottish Ten project commenced in late 2009, and set out to digitally document Scotland's five World Heritage sites and five international heritage sites, in order to better understand how to conserve and manage them. It has been delivered as a partnership between HS and DDS* (Scottish Ten, 2015).

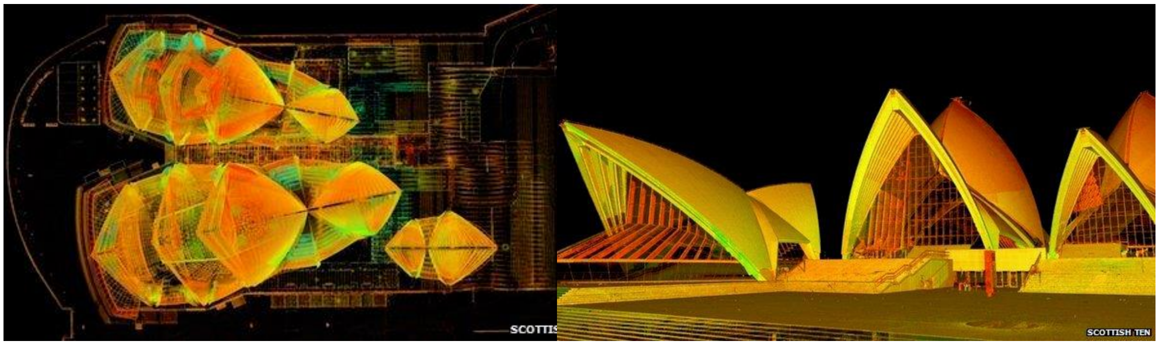

Figure 3 Scottish Ten Scanning (Linning, 2014a).

4.2. BIM FOR ASSET/FACILITY MANAGEMENT

We see BIM as a fairly key component of our future strategy for managing the building

SOH Interviewee (2015)

In 2013, the SOH started to develop a concerted strategy to implement a BIM interface solution for asset management. The team first requested an expression of interest submission through a pre-qualification questionnaire from which a short list of six organisations would be able to submit tenders. This second stage required consultants to create a detailed technical specification document of the proposed interface (Sydney Opera House, 2014b). Part of this effort included an end-user wish list survey, where system users were provided with the opportunity to express any capabilities that they would like to see in the new system. This solution will act as a centralised database and graphical interface for data associated with the management of the SOH asset and services, and is based on a BIM management plan. This document was developed through extensive research across international documents prepared by EAC (UK), American Institute of Architects, Revit, and previous SOH documentation (Sydney Opera House, 2014a).

The objective of the management plan is to maintain a controlled modelling process through a phased development. Providing a structured basis of guidance for users both familiar and new to the Sydney Opera House model, it is anticipated that portions of this document are used to inform deliverables for capital projects and models created by partnering organisations outside of the Opera House.

Sydney Opera House (2014a)

The BIM for FM solution implementation will occur in two stages in order to test *the robustness of the solution provided, and evolve the data linked to the model*: (i) fully functional BIM and basic functions of the solution; and (ii) additional modules of functional requirements (Sydney Opera House, 2014b). The first stage is expected to be rolled out in early September 2015.

The new BIM asset management system has the following purposes:

- *To provide an accurate 3D digital representation of the Sydney Opera House*
- *To act as the central placeholder for data associated with the management of the facility and services*
- *To act as a base for future projects at Sydney Opera House, endeavouring to alleviate survey works and existing building modelling being carried out on future projects* (Sydney Opera House, 2014a).

This system is expected to be a web based 3D graphical interface that will link an up-to-date *geo-spatially accurate model of the existing building and site to the major engineering documentation, maintenance and building management and control system*s. The system is planned to be the single source of information for *all regular building operational requirements, as well as on-going developmental works and projects*. In the long term, the system is expected to be integrated with the Building Management and Control System (BMCS), linked to the security cameras system and used for: interactive training and inductions; creating an active timeline of the building; way finding applications; visual analytics (Figure 4); and other functions. It is also required that the new system is accessible from hand-held devices with security, barcode reading and image recording features (Sydney Opera House, 2014b). Figure 5 provides a visual representation of the basic BIM interface for asset management functionalities.

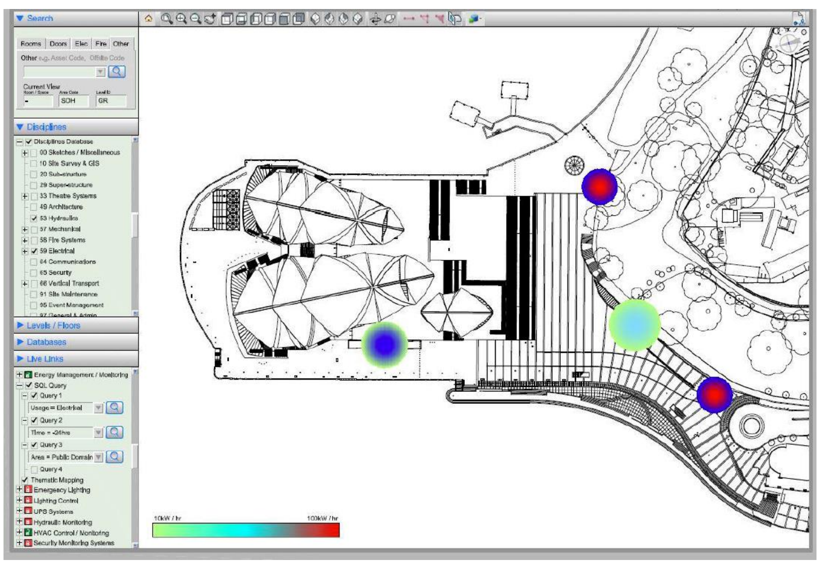

Figure 4 Sample View – Potential Visual Analytics (Linning, 2014a).

The SOH is currently considering using Omniclass[2] classification across the asset management system, integrating even financial and human resources systems. This classification is currently part of the standards used for construction projects (Sydney Opera House, 2011). They have also used the British

[2] *The OmniClass Construction Classification System is a classification system for the construction industry, developed by the Construction Standards Institute (CSI) and is used as a classification structure for electronic databases... OmniClass incorporates other existing systems currently in use, including MasterFormat™ for work results, UniFormat for elements, and EPIC (Electronic Product Information Cooperation) for structuring products* (Sydney Opera House, 2011).

standard PAS55 and the international standard ISO55000 to develop their BIM policy and strategy for asset management. These standards have also been used to develop the service contract documentation integrating recommendations from the CRC for Construction Innovation exemplar project.

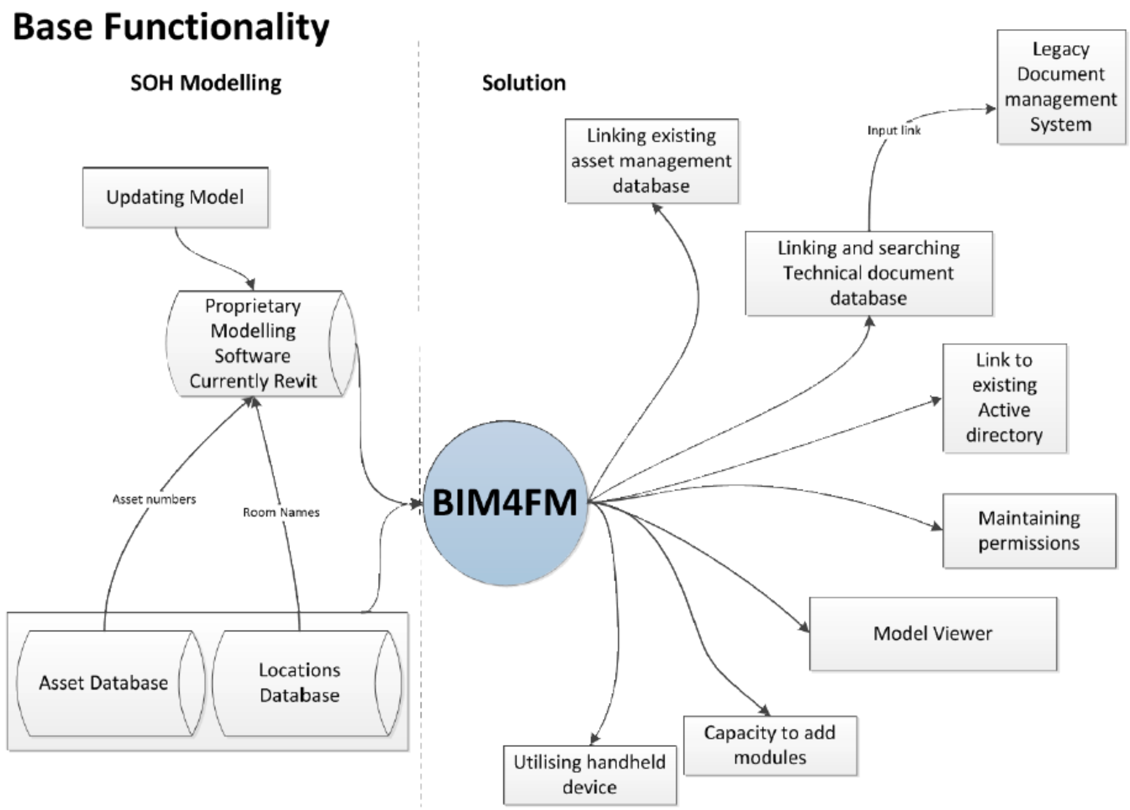

Figure 5 The BIM interface Base Functionality (Sydney Opera House, 2014b)

4.3. PERFORMANCE INDICATORS

> *Performance management, therefore, is all about timely performance measurement, and senior management not only need to have this information, they need to have it in a format that enables strategic decision-making.*

CRC for Construction Innovation (2007)

The CRC for Construction Innovation recommended developing KPIs that link service outcomes to asset condition and the role of FM as business enabler as well as using the model to support procurement processes. Based on this, they suggested the following service and asset KPI as examples (CRC for Construction Innovation, 2007)*:*

- Tour performance and number of people taking paid tours
- Customer satisfaction growth

- Building presentation index and cleanliness of the building compared to "as-new"
- Building fabric index[3].

This report (CRC for Construction Innovation, 2007) additionally mentions the following KPIs:

- *backlog liabilities*
- *cleaning and waste management*
- *energy*
- *grounds*
- *maintenance*
- *operating costs*
- *parking*
- *recycling*
- *refurbishment*
- *security*
- *statistical data*
- *water usage*
- *Cost of:*
    - *administration*
    - *airconditioning*
    - *carparking*
    - *cleaning*
    - *electricity*
    - *energy management*
    - *fire protection*
    - *gas and oil*
    - *insurance*
    - *landscaping*
    - *lifts and escalators*
    - *pest control*
    - *repairs and maintenance*
    - *security*
    - *supervision*

4.4. DRIVERS

> *The ability to own, reuse, and properly manage building data throughout the facility lifecycle accrues significant advantages for the Principal. Consequently, the accurate creation, management, and stewardship of building information during project creation is of utmost importance. Data created during construction and refined during the project execution process provides a valuable resource for facility management (FM).*
>
> Sydney Opera House (2011)

This research identified the following drivers for developing and implementing the BIM for asset management system in the SOH.

[3] *Building Fabric Index (BFI) and a Building Presentation Index (BPI), is a method the SOH has adopted to measure general appearance, tidiness and cleanliness of functional spaces of the building* (Linning, 2011).

4.4.1. SINGLE SOURCE OF INFORMATION

> *The primary driver for the BIM interface solution is to be able to retrieve technical documents and information from existing systems within an intuitive, visual search solution.*
>
> Sydney Opera House (2014b)

BIM has been seen as an opportunity to merge a number of disparate sources of information currently available in different databases… *just having one system where the data is fully integrated and you know is consistently working off the same baseline rather than having multiple systems* (SOH Interviewee, 2015). This ensures consistency and reliability across data sets.

4.4.2. COMPLEXITY OF THE ASSET

The complexity of the SOH results in having a large number of significantly different sections with different management requirements. In this sense having a 3D gateway was attractive to the management team. The use of BIM provides the opportunity to record elements that have been traditionally hidden from sight and difficult to pinpoint during refurbishment, repair and construction operations. For example, underground services and in-wall wiring recorded accurately in the BIM model, providing even images of the infrastructure before it is covered would reduce rework during future works.

4.4.3. SAFETY

Once the new asset management system is in place, the team expects to use the BIM model to plan and manage emergency responses as well as hazardous material tracking. It is envisioned that eventually emergency responders may have access to live feed of the CCTV cameras in the affected areas through the asset management interface as well as use the model for way finding and pinpointing hazardous materials.

4.4.4. ART PERFORMANCE REQUIREMENTS

Due to the functions of the SOH, the asset management requires the storage and tracking of a large number of materials and their information. This is currently saved in individual databases. Thus, being able to integrate them through a single interface would facilitate management.

4.4.5. SUSTAINABILITY

The building consumes significant quantities of energy and water. It is expected that the use of BIM will help SOH achieve their environmental sustainability targets. The second stage of development would aim to, for example, link the consumption meter to the model in order to produce better analyses and projections that can improve these aspects. By integrating a number of parameters such as cost, efficiency and other, it is expected that the system will help provide a more holistic approach to management and sourcing of plant and equipment that is also more economic.

4.4.6. HERITAGE LISTING

The SOH is a heritage-listed asset with an expected life-span in the order of hundreds of years. BIM offers the possibility of tracking the history of changes to the SOH, including both structure and infrastructure, and would be a powerful tool for heritage management and monitoring type systems. The fact that the SOH team has to plan for such a long life-cycle also provides an incentive to own the copyrights to any software solution and models developed specifically for the SOH.

4.5. CHALLENGES

The following section summarises the challenges identified over the course of the last 10 years in the development of their BIM for asset management strategy and system.

4.5.1. SOFTWARE LIMITATIONS/INADEQUACY

We seem to be a long way ahead of the software industry in what we were looking to achieve... So trying to work out a method of actually delivering an information model was kind of tricky.

SOH Interviewee (2015)

The SOH team often required software capabilities that did not exist commercially and had to wait for the industry to "catch-up". For example, during the VAPS project, a document type "BIM" was required within the project management software system. This led to the team approaching their project management software vendor who later developed the document type for use within the software.

In general, it was the view of the interviewees that the most challenging factor which led to the 10-year-long journey was the fact that the industry did not have commercially available software that were able to provide the capabilities required by the SOH.

Additionally, commercial software copyright limitations were also mentioned. It has been important to the SOH to not be "locked-in" with a provider. One of the requirements that has driven the development of their BIM asset management system has been to be able to modify the software and model as new needs are identified and technology progresses. The model should be easy to use and update. This requirement is driven by the fact that the building is in constant flux and the model will need to be changed in-house frequently. It was observed that common software platforms such as Revit tend to be too complex for asset management and some software developers have struggled with the idea of allowing the SOH to carry out in-house updates to the system. *Most important is that the solution and the technical document and information database are flexible and scalable. It is important… that they can add modules of different functionality to the solution, as well as adding more searchable databases and tables* (Sydney Opera House, 2014b).

In relation to software, it was also identified that a large proportion of the commercial BIM software packages have a specific focus on design and construction phases. However, the asset management and facility maintenance capabilities are seen as lagging. This is especially important for heritage buildings such as the SOH which are expected to be in operation for hundreds of years.

4.5.2. LIMITED FUNDS

Having access to funds to fully develop the BIM model for a building as complex as the SOH has been challenging. The CRC for Construction Innovation exemplar project and the Scottish Ten project however provided a starting point and reduced the cost of developing the model. Around 2004, the cost of modelling just the Opera Theatre was about AUD600,000, to model the balance of the building, the shells and internal structures was outside the SOH budget strategy.

4.5.3. DATA AVAILABILITY

Closely related to funds, the availability and creation of data that could be used for the development of the model was also identified as a challenge. Initially, most of the data available to the SOH were 2D drawings from the 80's. The work promoted by the CRC for Construction Innovation and undertaken by the Scottish Ten project helped address this challenge and the SOH team has been filling the data gaps since then. They have now developed a survey program to bring the whole building up-to-date and complement the data from the Scottish Ten and other construction projects carried out in BIM.

4.5.4. FINDING THE RIGHT ANSWER

Developing a strategy and logic behind the asset management system that would cover all the needs of the SOH precinct and services was identified as a challenge. To address this challenge, the SOH has engaged in research collaborations with a number of organisations such as the CRC for Construction Innovation, it has carried out extensive internal research and end-user consultation, and has engaged expert consultants such as BIMe and the BIM Academy.

Additionally, being able to understand what were the real capabilities of the organisations who submitted an expression of interest was also considered a challenge because of the variety of approaches offered. The SOH addressed this challenge by engaging BIMe as expert consultant for the evaluation process.

4.5.5. RESISTANCE TO CHANGE

Challenges included convincing specific SOH staff members to change the contract requirements so the deliverables would be limited to one hard copy and an electronic bookmarked copy that could be directly uploaded to the operations and management system.

Senior members of the construction teams have also had to adapt to the new way of working. Some of these roles showed resistance to a paperless project environment as well as tended to attribute any failure to the use of BIM. Resistance to change is also seen as a challenge due to the generational shift; new workforce generations will expect to work on 3D digital integrated environments and are likely to feel frustrated if forced to work on 2D due to senior management's resistance to this technology. On the other hand, it is frequently assumed that younger staff are familiar with the use of BIM, which is sometimes not the case.

Collaboration is seen as requiring the identification of professional strengths and weaknesses of individuals to create a dynamic well complemented team with good communication skills. However, the SOH has found a level of resistance to a more collaborative approach to delivering projects across the supply chain. For example, stakeholders accepting the fact that there is a single model of which all groups need to work from and trust that there is no need to redraw sections that affect them, and avoiding micromanagement of other roles that have different expertise areas.

4.5.6. PUBLIC ASSET GOVERNMENT REQUIREMENTS

The SOH is a public asset and is required to work within the boundaries imposed by the Government of New South Wales Asset Management Guidelines. At times, this has meant providing information in 2D drawings to the government instead of the 3D BIM models available.

4.5.7. AUSTRALIA'S GEOGRAPHIC ISOLATION

Australia's time zone has meant that many of the software developers are unable to provide support during working hours because the offices are based in the United States or Europe. This has made the SOH team more resourceful and innovative in many areas.

4.5.8. UNIQUENESS OF THE BUILDING

> *More than in most buildings, FM at Sydney Opera House is a core business function directly contributing to the visitor experience and therefore to the success of the business.*
>
> CRC for Construction Innovation (2007)

The SOH is considered a unique building due to its use pattern and type of equipment requirements. Therefore to apply a standard governance framework becomes challenging as well as predicting the useful life of plant and equipment. The SOH is opened seven days a week with equipment running depending on the day's performance schedule, therefore typical equipment use projections are not applicable. This has led the SOH to seek and develop more specialised approaches to asset management and governance.

We have unique needs and if we were to just go with a vanilla solution then the air conditioner would turn on at seven o'clock in the morning and turn off eleven o'clock at night and we would have consumed all that power we didn't need to (SOH Interviewee, 2015).

4.6. SUCCESS FACTORS

We are in this somewhat unique position to actually implement a true facilities management tool based on the hard work that's gone on for the last ten years trying to get all our systems to be compatible, streamlined and unique.

SOH Interviewee (2015)

The following were identified as success factors in the development of a BIM for asset management strategy.

4.6.1. INSPIRATION AND CORPORATE CULTURE

The SOH is among the most famous buildings in the world. The inspiration provided by this fact is considered to be a key factor in being able to engage "the right people" and successfully implement BIM for asset management. The design itself was observed to inspire the staff to be more innovative and this being ingrained in the organisational culture through strategic objectives that aspire to progress and innovation.

Because the building was built from the best practice… we're always questioning I guess and making sure are we doing it at the best?

SOH Interviewee (2015)

The iconic nature of the building has also inspired a significant level of attention from different stakeholders to seek establishing links to the SOH and contributing to the BIM for the asset management development journey. *People have assisted us and included us in the conversations of what they have been doing and what they can do to assist us* (SOH Interviewee, 2015).

4.6.2. EXTERNAL COLLABORATION

It was considered that interacting with other parts of the industry through collaborative research projects has provided the SOH with the opportunity to learn more about other initiatives that might be relevant and networking with other organisations to stay up-to-date.

4.6.3. CLIENT INVOLVEMENT

The fact that the SOH is the owner and operations manager was seen as success factor. This and the expected long life-span of the building has driven the SOH team to develop their systems with the future always in mind in order to "future proof" the building.

4.6.4. MANAGEMENT VISION

The leadership and vision of specific individuals within management was seen as a key factor that has helped the SOH develop their BIM strategy and scope, and is expected to be an important factor during implementation.

4.7. CLIENT APPROACH

The SOH has been in this BIM journey for ten years which has allowed them to carefully choose the standards and processes that best suit the needs of the precinct as well as becoming a well-informed client. This is seen as a risk mitigation strategy by allowing the SOH team to learn from the experiences of previous implementers and develop a system that perfectly suits their needs. Additionally, the SOH has seen becoming more informed and involved as a necessity due to the industry lagging behind in developing BIM solutions for asset management. This has also been driven by the observed tendency of commercial developers to promote "one-size-fits-all" solutions that would not suit the needs of the SOH. This role of well-informed and innovative client is often acknowledged by the industry by inviting SOH representatives to speak at conferences about BIM for FM as well as by the New South Wales Architect who has shown a focus on implementing BIM.

It was acknowledged that taking this more proactive approach requires more time investment in staying up-to-date with industry progress and requires a constant awareness of the consequences of decisions made, so *we're not painting ourselves into a corner in a dead-end solution* (SOH Interviewee, 2015). However, the benefits are considered to offset the cost. This approach will also help the SOH to understand the reasons behind decisions made in the system development and make better informed decisions in future scenarios.

Being a more involved client has also led the SOH to introduce non-price criteria in their tender evaluation which include the talent and skills that tenderers may bring to the SOH. The SOH has also developed a service performance scoring and management system based on the work initiated with the CRC for Construction Innovation.

4.7.1. DECISION-MAKING AND LEARNING PROCESS

The way you learn is by enquiring, by talking… and looking and listening to other people and taking on board what they have to offer.

SOH Interviewee (2015)

The decision-making process in the SOH regarding BIM system requirements and development are based on management trusting their team knowledge-based recommendations and self-education about BIM through attending industry forums and staying up-to-date. Additionally, the SOH has endeavoured in maintaining close ties with industry groups in order to learn from them.

If you want to succeed you have to take everyone on the journey with you.

SOH Interviewee (2015)

Stakeholder engagement and active dialogue are key parts of decision-making and learning processes in the SOH. This open-to-suggestions approach is reflected on their guidelines stating that *to achieve this final FMI system, Sydney Opera House BD&M portfolio is open to any suggestions and encourages conversations to advance BIM and its adoption* (Sydney Opera House, 2011). An example of this was the BIM for asset management scope development. Part of this process included a needs analysis and internal survey followed up by a workshop with end-users to gather a wish-list of the scope of the new system. In another example, the SOH started a peer-review process of the operation and maintenance information system. Outcomes of this effort were later used to produce standard templates.

The SOH also carries out a great deal of research into international best practices and published works in order to develop their own practice guidelines.

4.7.2. PREPARATION FOR TRANSITION

The main steps taken to prepare for the transition into the new system are:

- Data collection in formats that are interoperable with most systems
- Ensuring that construction projects capture and provide data required for new systems
- Ensuring that different software packages are compatible
- Developing a cultural change plan
- Understanding how services management will be affected and can be improved by the introduction of the new system
- Carry out user workshops to provide information about specific benefits, do stakeholder consultation and train users using standard systems.

4.8. EXPECTED CHALLENGES DURING IMPLEMENTATION

The following challenges during implementation are expected to be addressed in the coming months.

4.8.1. SKILLS AND TRAINING

A new skills and training strategy needs to be developed in order to ensure the new system is being used according to specifications and ensure quality of the data input.

4.8.2. ACCEPTANCE BY END-USER

It was seen as paramount to gain acceptance by end-users in order to ensure that the system is being used appropriately and to its maximum potential. If the end-users are not able to understand the potential benefits from using the new system it is possible that they will resist the change and revert to previous methods. Because they have never used a similar system before, it is possible that they will distrust the new work model. To address this risk the SOH is planning on working closely with system end-users, including at an individual level. It is expected that the initial wish list survey carried out to define the ideal BIM for asset management system will be useful in this transition. It will provide users with ownership over the changes made as they relate to their own wishes.

4.8.3. DATABASE INTEGRATION

Currently, the SOH has a number of databases used to manage the asset and several of these systems have their own barcode and identification classification. In order to transition into a fully integrated system, these databases will need to be analysed and "cleaned".

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6. APPENDICES

6.1. SYDNEY OPERA HOUSE BIM FOR FM OBJECTIVES

Objectives	Delivered to date
An information model integrating disparate software systems, all combined within a 3D model	Disparate proprietary systems are still the norm as we await s/w vendors to develop neutral solutions that utilise Open BIM protocols for Building System integration.
Progress to Achievement	30%
Model to provide comprehensive information on components	Our 3D model development still progresses, attempting to address the issues of as-built documentation. Contractors and sub-contractors still addressing the concept of returning object rich as-built model files at project completion. SOH BIM Guidelines (outlining model deliverables) are now included in all construction contracts.
Progress to Achievement	60%
Collaboration through open data exchange	Proprietary s/w files and IFC provide for most data transfers. Revit predominates as the tool of choice for most design/construction. The SOH BIM Interface Tender is encouraging the large BIM s/w houses to listen to the user needs rather than dictating user's requirements. Our solution is for OpenBIM.
Progress to Achievement	20%
Open data exchange standards	As IFC, COBie, SPie mature and become more accepted as viable data exchange, SOH has requested that they be used as part of document exchange and handover and will continue to advocate OPEN exchange standards.
Progress to Achievement	20%

Figure 6 Objectives under Digital Modelling. The "Delivered to Date" column is a brief summary of what has transpired to date and what is being implemented. "Progress to Achievement" provides a graphical representation of implementation (Linning, 2014b).

Service Oriented Architecture

Objectives	Delivered to date
Need to develop an SOA strategy for BIM	SOH Strategic Development team has workshopped the impact of BIM on other SOH systems/processes and is developing a master-plan for BIM rollout and BIM benefits to all.
Progress to Achievement	80%
Increased interoperability – information exchange, reusability, compatibility	Internal SOH data systems have been re-configured to a single data solution/provider to allow for greater interoperability of data resources. All new data requirements are required to be data compatible where possible.
Progress to Achievement	95%
Increased federation – united resources & applications but maintaining individuality, autonomy and self-governance	A single point of truth [SPOT] data set approach is being established rather than a dataset per application. Our IT/IS services maintain dataset integrity across all applications while working to achieve individual data specific requirements.
Progress to Achievement	85%
Increased business/technology domain alignment	Ongoing development with a majority of BMS applications meeting this requirement. The BIM Interface tender will enforce further alignment.
Progress to Achievement	90%

Figure 7 Objectives under Oriented Architecture. The "Delivered to Date" column is a brief summary of what has transpired to date and what is being implemented. "Progress to Achievement" provides a graphical representation of implementation (Linning, 2014b)

Enterprise Framework

Objectives	Delivered to date
Data management to achieve a single set of data definitions	Collaboration between SOH and contractors & consultants has driven the need for shared common libraries, specifications, guidelines etc. BIM Execution Plans, Model Management Plans & BIM Guidelines define these and are written into contracts to ensure system control and agreed protocols.
Progress to Achievement	90%
Capture the data rules of the Enterprise Framework	Data rules have been developed from a combination of international, national and user experiences based on practicalities of implementation. Data rules are prefaced with a "living document" clause to ensure ongoing practicality of process changes and cooperative agreement on how to manage such changes. Rules tend to be more guidelines than standards.
Progress to Achievement	90%
Provide reference framework to support data exchange between business domains and external organisations	The SOH BIM Execution Plan for the VAPS Project incorporates a Modelling Matrix – Exchange Protocol chart that identifies software apps and versions to be used during the course of the project. Any variations to these have to be agreed to by all parties. SOH BIM Guidelines provide numerous links to external reference sites for users to expand their understanding of BIM and welcome feedback to SOH in regard to BIM developments or procedural changes. Model Management Plans provide detailed guidelines for both internal and external technicians.
Progress to Achievement	90%
SOH developed/formalised guidelines & specifications to support FM processes (using IFC)	CAD Guidelines, BIM Guidelines, BIM Execution Plans, Model Management Plans, O&M Guidelines, Technical Numbering Papers, BIM Contract Clauses all form part of the set of reference documents included in contract documentation. These documents are "living documents" with formalised revision controls to ensure consistency between all parties.
Progress to Achievement	95%

Figure 8 Objectives under Enterprise Framework. The "Delivered to Date" column is a brief summary of what has transpired to date and what is being implemented. "Progress to Achievement" provides a graphical representation of implementation (Linning, 2014b)

Advantages of an Integrated Digital Model

Objectives	Delivered to date
Consistency of data	Agreed coordinates, origins, units, nomenclature form the guidelines to which data is developed, delivered and re-purposed. Where possible, only one source of data is maintained to ensure currency. Protocols are developed to continue this approach.
Progress to Achievement	95%
Intelligence in the model	Space identification (rooms/doors/floor coverings/paint finishes etc) has been fully developed. Point cloud scanning is being utilised to speed up "as-built" status of building. Future FM applications are intended to allow two-way, post-construction population of model and linking to extended dataset information. Master planning for this style of capture is underway.
Progress to Achievement	75%
Multiple representations	Already a single VAPS model is maintained during construction from which approx. 700+ drawing sheets have been created/maintained. The addition of the VAPS model into the SOH master model will provide a highly accurate internally managed federated model base for future building & life-cycle management .
Progress to Achievement	90%
Data source for other applications	IT/IS systems will link to the master model to provide data-mining functionality via thematic representation of queries. BIM Interface Stage 2 will extend to Fire Services, Security, Human Resources, office accommodation, event management, ticketing, virtual tours and day to day Facility Management Services.
Progress to Achievement	30%
Data mining through integrated queries	The "yet to be developed" frontend interface to the model and data systems shall provide intelligent dynamic access for data mining. From simple directional queries to complex environmental impact queries should be able to be undertaken based on user-login criteria. It is envisage that the final interface will be a web-based, non-proprietary, non-licenced solution to which SOH owns the code.
Progress to Achievement	30%
Linking to different data sets	The IT/IS planned integration of BIM into daily business needs will utilise the principles of OPEN BIM to its fullest to ensure flexibility and access to all datasets held on the SOH network. An internal federated BIM network is the intended solution that is being worked towards.
Progress to Achievement	30%
Potential non-proprietary solutions	SOH has developed and operates a selection of non-proprietary solutions. As stated above, the principles of OPEN BIM are paramount to ensure application development opportunities are not compromised. The potential for leveraging of such applications only gives a far wider scope of what can be achieved/delivered. SOH fully supports this approach.
Progress to Achievement	20%

Figure 9 Objectives under Advantages of an Integrated Digital Model. The "Delivered to Date" column a brief summary of what has transpired to date and what is being implemented. "Progress to Achievement" provides a graphical representation of implementation (Linning, 2014b)

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

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September 2015