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Construction Industry Business Environment

BIM – Implications for Government

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EXECUTIVE SUMMARY

As '*The Architect's Handbook of Professional Practice'* (cited by Riskus (2007) suggests, Building Information Modelling, or BIM, is "the use of virtual building information models to develop building design solutions, design documentation, and to analyse construction processes". We would suggest such a definition, while useful, should be extended to include the operational phases of built assets (such as maintenance and decommissioning), and also be applied to the whole area of infrastructure. As a set of technologies, BIM holds promise to deliver benefits for the property, construction, and infrastructure management industries – particularly improved efficiencies and effectiveness through enhanced collaboration at all stages of the construction cycle. There are several important qualifiers, barriers, enablers, and some disadvantages with this suite of technologies. This report outlines the costs and benefits enablers and barriers associated with BIM, and makes suggestions about how these issues may be addressed.

BIM as a suite of technologies has been enabled by the significant improvements in IT infrastructure, the capabilities of computer hardware and software, the increasing adoption of BIM, and the development of Industry Foundation Classes (IFC) which facilitate the sharing of information between firms. The report highlights the advantages of BIM, particularly the increased utility and speed, better data quality and enhanced fault finding in all construction phases. Additionally BIM promotes enhanced collaborations and visualisation of data mainly in the design and construction phase.

There are a number of barriers to the effective implementation of BIM. These include, somewhat paradoxically, a single detailed model (which precludes scenarios and development of detailed alternative designs); the need for three different interoperability standards for effective implementation; added work for the designer which needs to be recognised and remunerated; the size and complexity of BIM, which requires significant investment in human capital to enable the realisation of its full potential.

There are also a number of challenges to implementing BIM. The report has identified these as a range of issues concerning: IP, liability, risks and contracts, and the authenticity of users. Additionally, implementing BIM requires investment in new technology, skills training and development of news ways of collaboration. Finally, there are likely to be Trade Practices concerns as requiring certain technology owned by relatively few firms may limit trade.

Recommendations:

The report recommends that the espoused benefits of BIM be trialled through a series of pilot projects, where the utility of the tools and the ways in which barriers can be addressed are systematically tested in order to demonstrate their benefits across a range of built assets. It is further recommended that such pilot projects should examine the range of technological issues identified in this report, but should also examine the organisational, legal and contractual issues which have also been flagged as important for successful implementation of BIM.

Appendix A summarises several cases where BIM has been implemented, together with the lessons learned from these projects.

Additionally, the CRC for Construction Innovation has developed and is developing a suite of tools which can assist in the implementation of BIM by government. A summary of these tools and their applicability across the built asset life cycle is discussed in Appendix B.

1. AN INTRODUCTION TO BIM

Building Information Management, or BIM, is "the use of virtual building information models to develop building design solutions, design documentation, and to analyse construction processes" (The Architect's Handbook of Professional Practice' cited by Riskus 2007). BIM has considerable potential for enhancing the efficiency and effectiveness of the Architectural/Engineering/Construction/Facilities Management (AEC/FM) Industry as it extends the functionality and application of existing Computer-aided-design (CAD) technologies. The main extension is by linking the 3D built asset model to a relational database that can carry all information related to the built asset. This added functionality provides a mechanism for extended collaborations between designers, engineers, constructors, and facility managers across the life cycle of built assets. Another aspect of BIM is that information which is created once, can be re-used many times, resulting in less errors, greater consistency, clarity, accuracy, and clear responsibility of authorship. This paper argues that BIM holds considerable promise for enhancing a range of activities for government, with leading authors suggesting 20-30% increase in productivity when using the technology (Hartman and Fischer 2008 p.80). Despite the prediction that the uptake of BIM in the AEC/FM will be slow but inevitable (Goldberg 2005), there are some real barriers which need to be addressed in order for this adoption to occur.

This paper outlines these costs, benefits, barriers and enablers of BIM, and makes recommendations as to how the shortfalls can be addressed. Additionally, while BIM has been primarily explored in relation to buildings, there is little reason why the technologies could not also be applied to other infrastructure projects – e.g. dams, bridges, and tunnels. In order to reflect the utility of BIM for a wider range of construction activities than just buildings, this report will discuss the use of BIM in relation to a range of built assets, not just buildings. Where possible, examples are included in text. A more detailed summary of Instances in which BIM has been implemented has provided in Appendix A.

From the outset, this report argues that BIM has the potential for improving all stages of construction. Accordingly, it is appropriate to firstly provide an overview of the various phases of construction and subsequently how BIM might be implemented in these phases.

1.1 Application of BIM in the Phases of Construction

The life cycle of built assets typically have a number of different distinct stages, notably, design, construction, maintenance and decommissioning. Section 1.1.1 summarises these phases, for those unfamiliar with construction phases. Sections 1.1.2 to 1.1.5 subsequently examine how BIM can be applied in these various stages.

1.1.1 Phases of a built asset life cycle

Pre-Design: For clients and owners who have large or complex facilities, a planning or pre-design phase may also be important. In this stage project parameters and requirements are set so as to guide the design and construction, together with criteria to assess the outcomes and building performance.

Design: In the first phase of the built asset life cycle, an architect will work with the client to identify the client's needs and develop a written program, documenting those needs. The architect will then create a conceptual or schematic design. This early design, when approved, is then further developed and the architect will usually bring in other professionals, including mechanical, electrical, and plumbing engineers (MEP engineers), a structural engineer, sometimes a civil engineer and often a landscape architect to complete the design and the tender documents (drawings and specifications). Often these processes are coordinated by a Project Manager. These documents constitute the building design which are used in the second phase, that of construction.

Construct: In the second stage, the contractor sets out to construct the built asset according to the specifications set out in the design and documentation phase. Before construction starts, construction documents may be updated to incorporate addenda or changes. The contractor may have been appointed at an earlier design stage (e.g. a under managing contractor arrangement). The necessary approvals (such as the built asset permit) must be achieved from all jurisdictional authorities and the construction process can begin. In many instances, components of a project are supplied and installed by sub-contractors. The general contractor often provides work with its own workforces, but it is not uncommon for a general contractor to limit its role to management of the construction process and daily activity on a construction site. During the construction phase, the project manager and/or the architect acts as the owner's agent to review the progress of the work and to issue site instructions, change orders or other documentation necessary to the construction process. The construction stage generally ends at the moment the built asset is delivered to the owner.

Maintain: The third phase is maintenance. During the operational life of the built asset, the built asset will need to be maintained, a process which has generally become known as facilities management. The services are sometimes considered to be divided into 'hard services' and 'soft services'. Hard services include things as; ensuring that a built asset's air conditioning is operating efficiently, reliably, safely and legally. Soft services include things as; ensuring that the built asset is cleaned properly and regularly or monitoring the performance of contractors (e.g. builders, electricians). In some situations, the construction contractor provides the FM for a defined period of the life of the asset.

Renovation / Decommissioning: The fourth phase is either renovation or decommissioning. All built assets have a life cycle, and assessment needs to be made towards the end of the life cycles as to refurbishment, or decommissioning. Refurbishment has the potential of extending the usable life of a built asset. All built assets have finite life beyond which it is no longer economical to operate them. At this point they will be decommissioned; that is, they will be dismantled and their components disposed of either by sale or scrapping. In some cases the built assets may be put to other uses, or components of the built assets recycled for use in new built assets.

BIM has potential application for all of these phases, and is discussed in relation to each of these below.

1.1.2 The utility of BIM in the design phase

Historically, designing a built asset involved drawing a two dimensional (2D) image of the built asset on paper and making hard copies for other participants to use in the next phase - construction. In the early 1980's, architects started using CAD, or computer aided design, which allowed designs to be created on a computer in a 2D format and copied more easily. In the evolution from paper-based drafting to 2D CAD, the relationship between designers and contractors remained stable, with little change noted in procedures (Emmit and Gorse 2003; Gibson and Davis-Blake 2001; Taylor and Levitt 2007). The reason for this is that while CAD improved processes for architects as they designed built assets, the end product – a 2D drawing – was effectively the same. As Finch argues:

> CAD systems produced marginal benefits for many organisations over conventional drawing methods. This was because the electronic design invariably became committed to a hardcopy version at numerous stages. The electronic version was dispensed with and at each stage the drawing had to be recreated from scratch (Finch 2000).

While CAD enabled drawings to be created on a computer, in the end the drawings were converted to 2D hard copy, and handed over to the contractor. So up until the early 1990's, innovations driven by ICT only affected the design stage of the construction process. The remainder of the construction process remained relatively unchanged.

The introduction of Object Oriented CAD (OOCAD) systems in the early 1990's involved the replacement of 2D symbols in CAD drawings with built asset elements (objects) which were capable of representing the behaviour of common built asset elements. The key improvement of this technology was that these built asset elements could have non-graphic attributes assigned to them, and associations between the various elements of a built asset to be made (Batcheler and Howell 2005). Additionally, this new 3D computer technology enabled designers to better visualise a built asset, by being able to rotate the built asset and view it from multiple angles. The third, parallel development in the 1990's was the increasing use of internet for digital data sharing (Domikis, Douglas and Bisson 2006; OECD 2005). This increased use of object oriented modelling in the design phase, and the capability of the Internet to enable information sharing between geographically and temporally distant firms, resulted in the emergence of BIM as a set of technologies. As Tse et al. note:

> In line with the increasing computer hardware and software capability, most CAD vendors have launched more powerful object-based CAD software in recent years. These software programs are now commonly known as Building Information Modelling (BIM), Virtual Building, Parametric Modelling or Model-Based Design (Tse, Wong and K.W. 2005)

The latest developments in BIM technology mean that all of the 3D building objects created in the design phase, can coexist in a single 'project database', or 'virtual building', that captures everything known about the building. "A building information model (in theory) provides a single, logical, consistent source for all information associated with the building" (Batcheler and Howell 2005). Ibrahim et (2004) describe this process by stating;

> Instead of representing a wall two-dimensionally with two parallel lines, the wall object has properties that describe geometrical dimensions such as length, width and height as well as materials, finishes, specifications, manufacturer and price which are also included. Doors, windows, slabs, structural members, and stairs can be objectified in the same way (Ibrahim et al. 2004).

Additionally, the location of an object within a built asset can be pinpointed using unique geospatial referencing (Dempsey 2006) which can be incorporated into the model. An example of these relations is the following strain of links from an object: "A duct, having an asset code of *BSE-DU694* is installed on building storey *Level 3* of the building named *Block B* situated on a land parcel with Lot *No 1222546"* (Dempsey 2006).

In BIM, the model comprises individual built assets, sites or geographic information system (i.e. precise geometric coordinates coupled with accurate geometry and represented visually), with attributes that define their detailed description, and relationships, that specify the nature of the context with other objects. Because all components within a BIM are objectified and have properties and relationships attached to them, BIM is called a 'rich' model. In this way BIM offers a variety of information that is generated automatically as the design model is created. In turn this information can be used for cost estimating, project planning and control, sustainability (such as Life Cycle Analysis and Life Cycle Costing), and eventually for management of the operation and maintenance of the built asset (Salazar, Mokbel and Aboulezz 2006).

For government, BIM offers a digital modelling technology that offers the potential to integrate design, engineering, construction maintenance and decommissioning information about a built asset project into a single 'rich' model. Further, BIM technology enables the use of 3D drawings to be moved beyond the design phase and into the construction, maintenance and decommissioning phases of the built asset although few projects have been able to demonstrate this level of functionality to date.

1.1.3 The utility of BIM in the construction phase

The application of BIM to the construction phase is possible because the underlying data of the BIM contains rich data concerning not just individual elements of the model, but also the relationships between these elements. Cyon Research (2003) provides an example: "although a door has an independent existence, it will move with a wall in which it has been inserted"[1]. For designers and builders this means that amendments to building designs can be made rapidly, easily, and accurately as all of the related elements of a particular drawing are adjusted at the same time.

While the models created in BIM software, are detailed 3D representations of built assets, they are more than that. As Ashcraft (2006) argues, although BIM:

> can create 3D visualization, the model is not constructed from simple graphical elements. Instead, it is generated from a relational database containing information regarding the elements of a structure and their relationships (Ashcraft 2006).

Cyon Research extends this by suggesting built asset elements can contain:

> many non-geometric attributes, fire-resistance for example, or manufacturer's name and model number. This … makes for a realistic model; one who's every aspect is linked to every other aspect to reflect reality. A change made to any 'view' of the model, whether graphical or textual, is immediately reflected in every other view (Cyon 2003).

[1] Design professionals will recognise that the concept of 'parametric integrity' is being discussed here.

The elements of a built asset in a BIM model can include data concerning their composition, cost, manufacturer, relationship to other elements, and related properties such as dimensions, weight, fire-resistance or combustibility, etc. Such information becomes very useful for estimating costs and bills of quantity, etc.

An extra addition to this 3D parametric modelling is that it is also the basis for the possibility to apply 4D simulations. 4D is industry code for the addition of the element of time to a built asset model. A 4D simulation program is a software tool that automatically prepares construction schedules together to show a 3D simulation of the construction progress over time – which is where the idea of 4D originates. The process of assigning time to each of the elements of a 3D built asset model greatly reduces the chance of human errors in the construction process. Also the visualisation of the construction process enhances the understanding of the process involved, so that any issues can be identified by non-technical people and the visualisation may highlight constraints that had not been previously identified or made explicit (CRC for Construction Innovation 2005). 4D BIM can greatly enhance traditional project management software as the specific visual representation of construction elements are linked to specific points in time. A client and builder can see a visual representation of the state of the finalised building at any given point of time.

An example of this was given in the construction of a hospital, where the 4D model was shown to the clients (who worked for a large hospital) prior to construction (Fischer 2004).. The 4D model showed all the stages of the construction process, including the equipment needed to construct the built asset. When viewing the construction process, the gantries and large cranes planned to erect the building were also displayed. The hospital staff quickly pointed out that this equipment blocked the primary flight path of emergency helicopters to the helipad essential to the rest of the hospital; therefore such equipment could not be used. This had obvious implications for the construction planning process and considerable effort was required in order to resolve this issue. However, it was resolved prior to commencement of construction, thereby demonstrating the utility of BIM for not just the planning phase, but also the construction phase.

Williams (2008) provides a useful overview of how BIM has been used in the construction of a variety of transport infrastructure including bridges, viaducts and railway tunnels. 4D BIM is used in these applications to demonstrate not just the construction of the infrastructure itself, but also to show how traffic could keep flowing, although re-routed, at different stages of a sub way construction; how a section of a viaduct could be demolished and rebuilt in only 3 days, and what various construction options would look like if implemented. Examples of this are above ground versus underground highways and the impact this would have on a city's foreshore; and what the construction of a high rise building would look like at different times of the year.

There are also advantages for sub-contractors involved in the construction phase as the detailed designs facilitate computer controlled manufacturing, automated estimated / quoting, accurate off-site manufacture resulting in improved coordination and reduced time, and less waste.

For government BIM provides a way to better engage with clients in the design phase, but can also result in significant productivity improvements in the delivery of the built asset. The ability to provide detailed model which contains detailed specification of a built asset in one place, which enables the rapid identification of errors and collaboration between various design professionals. The functionality goes beyond the specific sit of the built asset itself, and has also been applied to the access, egress, traffic, equipment and other elements essential to the effective running of the project.

Just as the introduction of BIM in the design phase, had indirect advantages for the government, so to does the introduction of BIM in the construction phase. BIM allows for better cost estimates of the project. As every phase of the construction is modelled, unforseen costs can be eliminated in the planning phase, instead of 'fire fighting' behaviour during the project, which in general costs more time and money than estimated. In addition it also leads to a better service quality delivery, increased consultation, reduced disputes and reduced lead time. These advantages of BIM to the government will be discussed in detail later.

1.1.4 The utility of BIM in the Operations / Maintenance phase

BIM also has applicability to the maintenance phase of built assets. Since all the specifications for a built asset, down to an individual component level are recorded, BIM provides a repository of detailed information about the built asset and its components that can be used after the completion of the built asset for Facility Management (FM). The FM has easy and quick access to important information during the maintenance phase, and moreover can update this information over time, which can result in better management of the asset. This framework also means that the owner of the built asset can easily change from one facility manager to another, as only one single BIM file needs to be exchanged (Elliman and Pridmore 1999; NOIE 2001).

Facilities Management is “a business practice that optimises people, process, assets and the work environment to support delivery of the organisation’s business objectives” (FMA 1998). If maintained properly during construction, BIM can become a tool that can be used by the owner to manage and operate the structure or facility (Ashcraft 2006). According to the CRC *Construction Innovation* (2007), facilities management is one of Australia’s fastest growing industries which contributes significantly to the economy and employs a great number of people.

Recent statistics on the FM industry support this contention. According to Access Economics:

> The combined direct and indirect contribution of the FM industry in 2002/2003 was AUS$12.2 billion of value added, AUS$12.4 billion in GDP terms, and (full time equivalent) employment of 172,000 persons. The combined contributions represented 1.8%, 1.65% and 2.1% share of the corresponding Australian GDP and employment totals (Ballesty 2006)

The addition of BIM in the maintenance phase has particular utility for governments in the maintenance of a built asset. As BIM can contain all of the data concerning the components of a built asset, the condition of these components can also be entered and audited. Given the typical longevity of government built assets, and the current regime of contacting-out asset management to private firms, any given asset may have multiple firms contracted to maintain them. This presents a challenge for effective asset management, as the change of firms often results in loss of local knowledge about the built asset itself. BIM provides a tool which can retain records of all the updated data of the built asset. Additionally, if a particular building element were to fail, then the constructor or supplier of that particular asset could be readily identified, and contacted to provide a replacement element.

As there is one knowledge base for a built asset, multiple firms can be used to manage the built asset, as every facility manager would update the BIM with additional information. Such a data base would also provide a basis for auditing the performance of the facilities manager as well as the performance of the built asset itself. Additionally, switching from one facility manager to another is simplified, as the BIM contains all the needed information for a new facility manager. Thus BIM has the potential to reduce opportunistic behaviour from the facility manager and creates incentives for the facility manager to perform as best as possible.

For government, there would appear to be great benefit in using BIM models for FM applications, as BIM can be used to integrate “a digital description of a built asset with all the elements that contribute to its ongoing function such as air conditioning, maintenance, cleaning or refurbishment and describe the relationship between each element” (CRC for Construction Innovation 2005). The Sydney Opera House FM Exemplar Project is an example of BIM used as a facilities maintenance tool (Akhurst and Gillespie 2006; Ballesty 2006; CRC for Construction Innovation 2005). There are advantages to a computer model which can be handed on from one contractor to another in contracting-out regimes, the primarily advantage being continuity of available information from one FM contractor to the next, thus enhancing the stewardship of such assets in contracting-out regimes.

1.1.5 The utility of BIM in the Decommissioning phase

At the end of the built asset life, when it is decommissioned, BIM is useful in supplying the information of the built asset construction, materials and the whole life history. From the BIM, information about hazardous built asset materials or elements was used in the built asset or in repair work can be identified and these can be extracted and stored as deemed appropriate. This readily availability of the data will increase the speed at which the built asset can be decommissioned and will also increase the safety of the decommissioning. As some built asset products are only deemed hazardous many years after construction (e.g. Asbestos), having a detailed database available of the built asset and the composition of its components greatly assists in the management of risk. Also BIM increases the overall sustainability of the built asset as it allows the identification of dangerous materials that require special handling and valuable materials that can be re-used. It also can assist possible future needs for dismantling built assets and reusing the entire built asset or components of a built asset, instead of simply demolishing the built asset.

For government, having a detailed model of a built ready that contains the composition of all elements of the structure, enables the identification of (potentially) hazardous materials like lead and asbestos. Some construction materials are recognised as being hazardous long after their incorporation into the built asset. Just like the evolution of asbestos from a renowned built asset material to a dangerous substance, currently used materials can in the future be classified as dangerous. The availability of a BIM can help in identifying where and how often these materials were used. Additionally, some components of a built asset could still hold considerable value, such as copper, and could be re-used in an economically viable manner.

1.2 Summary of the implications of BIM for stages of construction

BIM holds the promise of being an important factor in the built asset industry in the future. As shown above, it can facilitate the users of all stages of the built asset life-cycle. It integrates design, engineering, construction maintenance and decommissioning information about a built asset project into a single 'rich' model. As such, BIM technology enables the use of 3D built asset models to move beyond the design phase, and into the construction and maintenance phase of the built asset as well as move the 3D model into a 4D simulation. Table 1 summarises these implications.

Table 1 – The application of BIM to various Stages of Construction (adapted and expanded from Hartman and Fischer (2008)[2]

Design	Construction	Operations / Facilities Management	Decommissioning
• Ensure the right facility is designed. • Evaluate the design from many perspectives. • Evaluate the design against building codes and sustainability before construction.	• More productive crews, as there are fewer changes to design once construction has started, the ability to track work in real time, faster flow of resources and site management. • Enables demonstration of the construction process, including access and egress, traffic flows, site materials, machinery, etc. • Better tracking of cost control and cash flow – particularly for large projects	• Keep track of built asset • Manage the facility proactively. • Such a model can be handed from one contractor to another, thus enhancing facilities management. • Capability to schedule maintenance and review maintenance history	• Identify elements which can be recycled or those which require particular care (e.g. Hazardous materials). • Know the composition of structures prior to demolition.

For procurement, BIM offers the opportunity to develop better cost estimates based on actual elements of the built asset, better design and construction processes and methods, and a means to engage the client in the design phase of the built asset (Hartman and Fischer 2008)

Much of the potential for BIM has yet to be realised due to the current level of development. As Ashcraft comments:

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[2] Hartman and Fischer (2008) also argue that BIM can enhance procurement processes. However procurement could apply to any or all of the construction phases discussed here, so this is issue is addressed section xxx. Likewise Building Smart (2007) argued that BIM had application for increasing the speed of Development Assessment approvals through local councils.

> In current practice, BIM is a hybrid, with several differing approaches being used. … Each approach seeks to tighten integration, but the single universal model and perfect interoperability are still aspirations, not achievements (Ashcraft 2006).

While not yet fully developed or applied to its full potential, there have already been instances where BIM or similar systems have been applied in the AEC/FM industry. The next section (Section 2) will deal with the advantages and enablers of BIM for government. This will be followed by Section 3 on the disadvantages and barriers of BIM for government. Section 4 provides a number of recommendations concerning the adoption of BIM by government. At the end of the report Appendix A provides a number of examples of how BIM has been applied in a variety of projects. Appendix B outlines a number of BIM applications developed by the CRC for Construction Innovation.

2. Advantages, Enablers and Applications of BIM

BIM is held to offer a range of advantages over hand-drawn or 2D models of built assets, which are discussed in the Section 2.1 below. As suggested in the introduction, BIM has emerged alongside a number of other technological and social accomplishments which have enabled BIM as a technology to be developed, which are discussed in Section 2.2 which follows.

2.1 Advantages of BIM for government

Using a BIM model has a number of advantages over traditional 2D approaches to design and construction. BIM models can enable collaboration between different professionals involved in the design and construction phase of the built asset, and can manage changes to the built asset design so that a change to any part of the built asset model is coordinated in all other parts of the model and underlying database, together with the capability of capturing and preserving information for reuse by additional industry-specific applications (Ashcraft 2006; Emmit and Gorse 2003; Gibson and Davis-Blake 2001; Taylor and Levitt 2007). BIM models can also offer a wealth of information that is generated automatically as the model is created. In turn this information can be used for cost estimating, project planning and control, and eventually for management of the operation and maintenance of the built asset (Salazar et al. 2006). The following benefits of BIM have been identified from the literature, which are explored in detail below:

- Increased utility and speed
- Enhanced collaborations
- Better data quality
- Visualisation of data
- Enhanced fault finding

2.1.1 Increased utility and speed

As noted in the introduction, the typical built asset lifecycle consists of four phases. These are the design phase, the construction phase, the management / maintenance phase and the decommissioning phase. In the current general practices, in each of these phases different programs are used. Architects use CAD programmes such as ArchiCAD, Revit , or Bentley Architecture. Engineers use various programs such as revit Structures or Tekla, and the construction sector and the built asset managers usually fall back to 2D blueprints of the built asset. These differences in approaches together with differences in jargon or terminology used can greatly hinder communications and unnecessary increase the time needed to finish the project. The CRC for Construction Innovation (2007) has calculated that the use of BIM can reduce the project time by at least 7%. This is achievable because BIM can offer all the stakeholders in the built asset lifecycle access to critical information, including schedule and budget information, materials quality and costing information, performance, utilization, and financial information (Dubois 2006; Evelyn and Fatt 2005), together with the benefits of off-site manufacture noted earlier.

Design phase

BIM is useful in the design phase where it gives support to the design, scheduling and budgeting of the built asset (Autodesk 2003). Safety and sustainability have become significant public policy issues facing the construction industry over recent years. As built assets perform a broad social and economic role in our cities, designers are balancing form-making with built asset performance concerns to increase the utility of the built asset. These issues such as life safety, security and sustainability are becoming defining characteristics of quality design in this new realm of performative architecture (Dubois 2006; Evelyn and Fatt 2005). This change in thinking about built assets requires a change in thinking for the designer, and BIM provides a platform to help the designer make this evolution. This process of assistance is described by Ibrahim et al. (2004) as:

> Architects do not need to acquire all the needed knowledge as a structural engineer to model the structural systems in a BIM based CAD system, nor all the technical knowledge to detail components that do not affect the final look of the built asset, on the contrary, architects tend to use catalogues of vendors to select components and use the offered details if it is suitable for the job (Ibrahim et al. 2004).

The speed of the design phase can be increased using the 'rich' database as provided with the BIM as less communication with the engineers is required. It also increases the utility as more features such as safety, sustainability and security become part of the design phase.

Construction phase

BIM is also increasing speed and utility in the construction phase, where it can aid the quality of schedules and cost information (Autodesk 2003; Fallon and Palmer 2007). Using the 'rich' database, containing all the structural and information components of the BIM, can not only increase the efficient interaction between the architect and the engineer, but it also increases the interaction between the designers and the contractor. The contractor has access to all the critical information that is needed inside the BIM database. This decreases the time that is needed to get back to the designer on certain parts of the project. It also decreases the time budgets and schedules are re-calculated after changes in the project, allowing the contractor to continue working sooner after said changes. By combining mobile technologies with BIM models, faults and reworking time can be greatly enhanced. A site manager can identify a fault; notify project management of the specific nature and location of the fault, due to the GIS location in the model, which in turn reduces rework time.

Maintenance phase

BIM also increases performance, utilization and financial information (Autodesk 2003; Fallon and Palmer 2007) in the maintenance phase. As all the design and built asset information is still present in the single BIM model, the maintenance manager has easy and quick access to important information during the maintenance phase. For example, when a glass window needs to be replaced, the manager can simply locate the window in the model, read out the specifications of the window, and simply place the order without even having to come into the built asset to measure the window. For infrastructure assets the conditions of various parts of a bridge or tunnel can also be located in a bridge, so that condition monitoring of specific elements is recorded.

Other uses for which BIM could be used include security, emergency evacuation, fire simulation, space management, move management, energy use monitoring, condition monitoring, and comparison of actual building performance against performance predicted in the design phase.

The largest increase in utility and speed can however only be achieved if every link in the cycle cooperates in the process, but when that happens, the implementation of such an organizational boundary spanning information system, as numerous research investigations have proven, are the source for competitive advantage (Taylor and Levitt 2007).

Decommissioning phase

At the end of the built asset life, when it is decommissioned, BIM is useful in supplying the information of the built asset construction, materials and the whole life history. From the BIM dangerous built asset materials like asbestos can be identified, as can any valuable materials used. This readily availability of the data will increase the speed at which the built asset can be decommissioned and will also increase the safety of the decommissioning.

Summary

The advantages of the design and the construction phase indicate that BIM can reduce the start-up time of a project. For government this time saved in starting a new project, translates to reduced costs – both financial and in-kind. Such savings would enhance the ability of government to build sustainable assets and set a great example for industry. Once the BIM model is constructed, the speed and utility of maintaining a built asset is greatly increased. Governments will have to spend less time checking and securing maintenance, as repairs and maintenance are easier performed, and audited. Should maintenance firms be replaced, which often happens in the life time of a built asset, the change in contractors typically means the loss of data on the condition of the asset, particularly if the contractor had been in place for a significant period of time. Having a BIM model means that knowledge of the asset is kept by the client, and easily shared with new contractors or the actions of multiple contractors can be coordinated through the single rich data base model. At the end of life of the built asset the extra speed at which it can be decommissioned safes time, money and reduces environmental damage. There is a key opportunity for government to set a great example for industry and society by operating in an efficient and sustainable manner. The opportunity for increased utility and speed from BIM provides an opportunity for cost savings for government. In order to facilitate such activities policy changes would be needed which trial the implementation of BIM in a number of settings. If these tests validate the use of BIM then consideration concerning the use of BIM across the portfolio of government built assets could be considered.

2.1.2 Better data quality

BIM provides better data quality, guaranteeing a flexible documentation output and full exploitation of available ICT technology. This is possible because BIM data handling is based on three characteristics, namely;

1. To create and operate on digital databases for collaboration
2. To manage change throughout those databases so that a change to any part of the database is coordinated in all other parts
3. To capture and preserve information for reuse by additional industry-specific applications (AIA 1997; Autodesk 2002; CRC for Construction Innovation 2005).

Design phase & construction phase

Better data quality is realized through the underlying basis that BIM uses one singe file on a server. Every user has access to this server at the same time. This means that changes are automatically updated through the model and thereby ensures that every user is working on the latest version of the model. This reduces errors that are prone to arise while using several different versions of a design and trying to manage the updates of the design across multiple sites or copies.

As noted earlier, the 4D BIM models also allow for demonstration of how the construction project would affect traffic flows, access and egress, public transport, and storage of materials on site, and the scheduling of machinery and personnel. This better quality of data – particularly as the data is visual and can be viewed over time, enables better outcomes in the design and construction phase. This potential has been demonstrated in a number of projects. For sub-contractors, the better data quality results in improved off-site manufacturing and fabrication, co-ordination, clash detection, etc.

For example, an ‘Engineers Australia Queensland Division Task Force 2005’ report states that 60 to 90% of all project variations are the result of poor project design documentation. BIM provides a very effective way of significantly improving design and documentation quality (CRC for Construction Innovation 2007). Furthermore, the Stanford University Centre for Integrated Facility Engineering has calculated, based on 32 major projects using BIM, that the following benefits were achieved:

- A 40% elimination of unbudgeted change
- Cost estimation accuracy within 3%
- An 80% reduction in the time taken to generate a cost estimate
- A saving of 10% of the contract value through clash detection
- A 7% reduction in project time

- A return on investment when using a 3D model of 5-10 times (SUCIFE 2007)

Thus, implementation of BIM in the design and construction phase is held to result in significant savings due to better quality data.

Maintenance phase

The additional design, construction and operational information contained in the BIM can be used after the construction in the Facility Management (FM) of the built asset. Having a complete 3D or 4D model of a built asset, which includes all of the elements of a building, their composition and condition, can lead to better management of the asset because all the data created while designing, constructing and maintaining the built asset will be stored in the same file. This also means that the owner of the built asset can easily change from one facility manager to another, as only the BIM needs to be exchanged. eBusiness technologies such as BIM, have the potential to transfer complex design information accurately (Elliman and Pridmore 1999), thereby eliminating data transfer error (NOIE 2001) as well as minimising delays as information is conveyed along the supply chain (Lee and Sexton 2007).

Better data quality in the design, construction and maintenance phase reduces the number of errors made in these phases, resulting in reduced working times, less cost and a higher efficiency. Some estimates suggest that Governments application of BIM in their built asset projects can ultimately achieve a return 5-10 times higher on the investment.

Decommissioning phase

Built assets typically last a significant length of time, and it is rare that the original designers and constructors are available to give advice on the composition of specific building elements – even assuming they could remember something that happened 50 years earlier. A 3D BIM model can serve as a long term repository of information which can greatly assist in the decommissioning phase – particularly the removal of some of the surprises and guess work which can be associated with certain types of asset.

2.1.3 Visualisation of the data

Design phase & construction phase

The 3D visualisation of the model as accomplished by the BIM is an added value for several stages of the built assets lifecycle. In the design phase the "3D visualization leaves little room for misinterpretation by all parties involved and it helps to realign their expectations as compared to what a bar chart schedule can do" (Salazar et al. 2006). An added feature of the BIM is that it can also progress the 3D model over time, creating a 4D simulation. A visualisation of the construction process as a 4D model greatly enhances the understanding of the process and identifies construction issues not only with technical persons, but also non-technical persons can in this way identify themselves with the built asset process and identify possible problems in the built asset process. This is possible because the visualisation may highlight constraints that the client had not made explicit earlier, or were misunderstood.

2.1.4 Enhanced fault finding – clash detection (process and product)

Design phase & construction phase

BIM enhances the fault finding capacity in the project immensely. Because all aspects of a project are driven from a single database or related databases, the project is always up to date. This helps in reducing issues regarding drawing coordination and conflict errors. The key benefit of the single integrated data environment is that integration of information from multiple disciplines creates an accurate geometrical representation of all parts of a built asset (CRC for Construction Innovation 2005).

BIM, as explained earlier, also supports project visualization, simulation and optimization and allows BIM to reduce design conflict issues by integrating all the key systems into the model. Design BIM systems can detect internal conflicts and model viewing systems can detect and highlight conflicts between the models and other information imported into the viewer. The solution can then be checked to ensure that it resolves the problem and to determine if it creates other, unintended, consequences (Ashcraft 2006).

Combined, the single BIM file, with the underlying continuously updated database containing parametric consistency, and the 3D and 4D visualisations, BIM is possible to greatly reduce the changes for errors in the design and construction phases of the built asset construction.

Such fault finding also carries through to the maintenance phase, as the condition of specific building elements can be assessed and recorded, and repairs initiated to specific elements at specific locations.

2.1.5 Enhanced collaborations across discipline and organisation

Design phase & construction phase

BIM helps in analysing built asset proposals, performance benchmarking and enabling improved and innovative solutions as well as quickly performing simulations. BIM is able to perform these functions across multiple stages of the built asset process and across disciplines and organisations. The rich database connected to the boundary objects of the model plays a mediating role to connect the disparate social worlds of the designers and contractors (Taylor and Levitt 2007). Because both designers and contractors use the same model, contractors can act swiftly on engineering problems faced by the designers, and visa versa. Construction firms are able to more clearly articulate their knowledge of constructability issues and request changes to the model that otherwise would have had to be worked out in the field during construction or later ‘with a hammer’ (Taylor and Levitt 2007). Because both designers and constructors have access to the model at the same time, this parallel process allows them to reduce lead times which normally occur in the sending back-and-forth of a paper plan between both groups. In other words, the application of BIM addresses and proposes a solution for the disputes that can arise between the design and construction phase, smoothing out these problems by creating a single digital environment in which both the designer and the constructor know their way around.

There are also certain advantages to a computer model which can be handed on from one contractor to another in contracting-out regimes, the primarily advantage being continuity of available information from one contractor to the next, for example:

> In a typical scenario, the architect would extract information from the model for use in calculating a wide range performance characteristic, such as heat/loss gain, day lighting effects, air flow, and egress under emergency conditions, structural performance and financial feasibility. Specialized knowledge would no longer be needed for data input or interpreting of results, creating a closer linkage between analysis and design process (Autodesk 2003)

BIM enables easier calculation of performance characteristics using the built in software and specialised personnel are no longer needed to perform these calculations independent from the design drawings.

A secondary benefit from the implementation of these design programmes is that firms that successfully implemented 3D CAD programmes, have improved collaboration, develop partnerships, or move beyond partnerships to understanding each other’s shared interests as described by Taylor and Levitt: “Finally they [*the design and engineering firms*] even redistribute work among firms, developed standards for interaction, and developed a system of understanding of the project” (Taylor and Levitt 2007). More design iterations are also possible for comparison, as they provide more feedback and better design solutions to achieve higher performance and conformity to the design brief. For example, improved energy usage, sustainability options and star rating can be enhanced through developing a series of iteration of the building design, which are sequentially tested for performance.

2.1.6 Summary of BIM advantages

As discussed in the previous section, BIM has several benefits. These benefits are not achieved in all phases of the built asset life-cycle. Although all benefits are applicable for the design and construction phase, the maintenance and decommissioning phase benefit most from the increased speed and utility, better data quality and the visualisation of the data. In table 1 these benefits have been summarised:

Table 2: The benefits of using Business Information Modelling

The key advantage of BIM is its accurate geometrical representation of all the parts of a built asset capturing all necessary and relevant data of every part in an integrated environment. The benefits of this integration are:	
<u>Benefit:</u>	**<u>Result:</u>**
- *Increased utility and speed* (In all phases)	Information is more easily shared, can be value-added and reused
- *Enhanced collaborations* (Mainly in the design and construction phase)	Across discipline and organisation, built asset proposals can be rigorously analysed, simulations can be performed quickly and performance benchmarked, enabling improved and innovative solutions
- *Better data quality* (In all phases)	Documentation output is flexible and exploits automation. Requirements, design, construction and operational information can be used in FM resulting in better management of assets
- *Visualisation of data* (Mainly in the design and construction phase)	The added value of 3D visualization leaves little room for misinterpretation by all parties involved and it helps to realign their expectations
- *Enhanced fault finding* (In all phases)	BIM greatly reduces conflict issues by integrating all the key systems into the model. Design BIM systems can detect internal conflicts and model viewing systems can detect and highlight conflicts between the models and other information imported into the viewer

Having reviewed the benefits of BIM across the project life cycle, it is appropriate to note some of the factors which are enabling the growth and uptake of the technology.

While some governments have mandated the adoption of BIM, this has been following extensive use of pilot studies which have trialled a number of BIM applications in a number of settings (e.g. GSA in the USA (Dakan 2006). Demonstration projects are likely to be necessary prior to use of other policy instruments such as education, regulation and policy.

2.2 Enablers of BIM

For the implementation of BIM there are have been three major enablers. The first is the advent of enhanced IT infrastructure and capability of computers to develop and display 3D models with underlying large databases. The second enabler is the creation of the Industry Foundation Classes (IFC) by the International Alliance for Interoperability (IAI). The third the increasing world wide support for BIM. These enablers will be explained in detail below.

2.2.1 Increase in computer technology and IT infrastructure

The internet, as a global self-regulated and interconnected network of institutions driven by educational and subsequently commercial priorities, has evolved into an element within a broader "global information society"

(Christopher 2008). The internet is one of the driving forces of globalization, and there is a strong correlation between exporting products and services and internet access at the enterprise level (Clarke 2008). At a practical level, the internet and roll out of high speed broadband across OECD countries has facilitated the exchange and sharing of large files across time and space. This has meant that firms can be separated geographically and operate in separate time zones, and yet the Internet enables these firms to collaborate on major projects. Continuous innovations in internet technology and IT infrastructure have inturn increased the performance of BIM.

Additionally enhanced computer capacity in processing power and graphics, storage and memory (Brodlie et al 2005) not to mention better compression algorithms, have meant that larger, more resource intensive files can be created and shared. This enhanced capacity of computers is one of the enablers for BIM technology. The current trend in IT infrastructure, with the latest innovation of fibre optic cables, gives rise to the possibility of sharing ever larger data files among users all over the world. BIM is heavily reliant on this infrastructure, since BIM files are large and need to be accessible at all times. Thus the internet, IT infrastructure and enhanced capacity of computers have all served as enablers of the creation of large, graphical models with huge databases embedded in the models.

The current development of eGovernment systems, can lead to a new organisational architecture and new ways of doing business and delivering services. In the built asset management sector of the government BIM can enhance the facility management for the government. Harris described that the need to deliver services differently the government needs to change the organisation:

> In order to deliver a service differently there is often a need to restructure the organisation and to engage in dialogue within the organisation and between organisations. This contact and 'opening up' of communication channels and developing co-operative arrangements in itself can lead to further synergies in terms of more information sharing, collaboration and examining new ways to effectively deliver services (Harris and Cornelius 2003).

The widespread adoption of BIM for AEC/FM industry could possibly be the catalyst to speed up this process, as BIM requires the development of new communication channels and co-operative agreements. The OECD sets out its case for eGovernment in terms of efficiency gains (savings in data collection, information provision, communications with clients and transaction costs) and service improvements (improved customer focus for service delivery and increased accessibility to services) (OECD 2003).

Enhanced capability is not enough however. There needs to be specific protocols which enable the sharing of information between firms and software packages. This is discussed next.

2.2.2 buildingSMART (International Alliance for Interoperability)

Interoperability can be described as "the sharing and exchanging of information via integrated technological solutions, no matter what project phase, discipline or participant role in the built asset life cycle" (AIA 1997). Although BIM may be considered as an independent concept, in practice, the business benefits of BIM are dependent on the shared utilisation and value-added creation of integrated model data across multiple firms. To access model data therefore requires an *information protocol*, and although several vendors have their own proprietary database formats, the only open global standard is that published by buildingSMART called the Industry Foundation Classes (IFC).

There are several reasons for the buildingSMARTto create a global standard for the built asset sector. One of those is the huge added cost of coordination errors. "Effectively, the historic inefficiencies of the built asset process have driven the industry to look at a new approach to the built asset process. According to the Construction Users Roundtable member companies in the US, it is generally accepted that as much as 30% of the cost of construction is wasted in the field due to coordination errors, wasted materials, labour inefficiencies, and other problems" (AGC 2006; CURT 2004).

In addition to that, in 2004, the National Institute of Standards and Technology (NIST) conducted a study on the cost of inadequate interoperability in the United States' Capital Facilities Industry. The NIST study involved "design, engineering, facilities management, business processes software systems, and redundant paper records management across all facility life-cycle phases. It estimated the cost of inadequate interoperability to be roughly

$15.8 billion per year, and of these costs, two-thirds are borne by owners and operators" (Gallaher, O'Conner, Dettbarn and Gilday 2004).

In order to address this waste of resources, money and time, the IAI is most responsible for promoting interoperability to the AEC/FM industry. buildingSMART is a global, industry-based consortium for AEC and FM. It was formed in 1994 and their mission is "to enable interoperability among industry processes of all different professional domains in AEC/FM projects by allowing the computer applications used by all project participants to share and exchange project information" (Froese and Yu 1999). Originally, buildingSMART's main objective was to "define, publish and promote specifications for IFC as a basis for project information sharing in the built asset industry" (Bazjanac 2002). buildingSMART currently has more than 400 members in 24 countries and is the leading interoperability organization (Ashcraft 2006).

> The integration of the AEC industry and the interoperability of the hundreds of software applications supporting the design and construction of the built environment have been providing one of the most challenging environments for the application of information and communication technologies (Turk, Dolenc, Nabrzyski, Katranuschkov, Balaton, Balder and Hannus 2004).

buildingSMART's stimulus in developing the IFC protocol was the recognition that the greatest problem in the construction industry today is the management of information about the built environment. Although every other business sector has embraced IT and adopted industry specific standards, the construction industry worldwide has stuck to its trade-based roots and dependence on drawings, with a continuing record of poor quality, low investment value and poor financial rewards. (CRC for Construction Innovation 2007)

The Industry Foundation Classes (IFC) are a set of rules and protocols that describe and store built asset information. According to Howell and Batcheler (2005), the "effort to define a single built asset model as one authoritative semantic definition of built asset elements, their properties and inter-relationships" has been largely successful. Bazjanac (2004) describes IFC as "the first open object oriented comprehensive data model of built asset that provides rules and protocols for definitions that span the entire life of a built asset". IFC are also the only such model that is an international standard (ISO/PAS 16739). Presently IFC are the only non-proprietary intelligent, comprehensive and universal data model of built assets (Bazjanac 2004).

The creation and existence of these Industry Foundation Classes, and the increasingly wide spread use of them throughout the industry enable the implementation of BIM in the built asset sector. When all the sectors of the built asset industry are using IFCs as the standard protocol, the sharing of data, as required by BIM is increasingly easier and barriers due to incompatibility of standards and protocols are reduced.

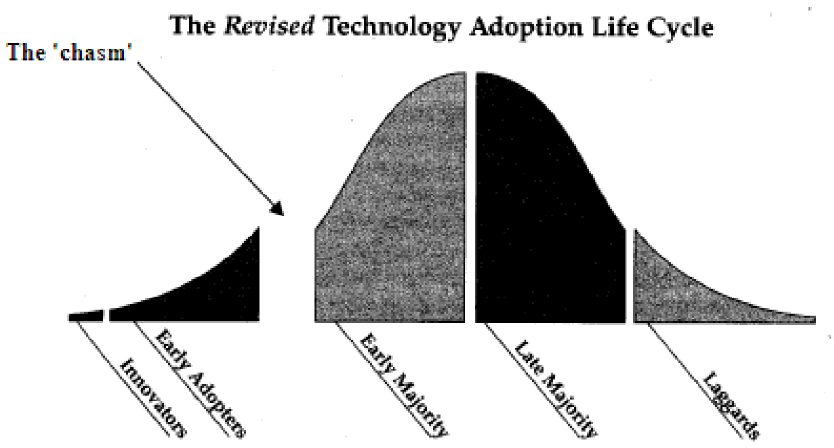
Capability of software and hardware to undertake a specific task, to a certain level of performance, is important. Demand for hardware and software that can perform these tasks is what will ensure there is continued investment in the hardware and software which make this possible. Some government organisations have mandated the use of IFCs, such as Finland and the United States of America.

2.2.3 Increasing World Wide Support for BIM

There is an increasing world wide support for BIM. According to a 2006 survey conducted by the American Institute of Architects (AIA), 16% of AIA member-owned architecture firms have acquired BIM software, and 64% of these firms are using BIM for billable work (Riskus 2007). The same survey found that "35% of the AIA member-owned firms with an international scope of practice have acquired BIM software, which may be at least partially due to the fact that firms with an international scope tend to be large in terms of staff and billings, and may also be working on large projects. But BIM may also simplify overseas projects, as it allows for easy transmission of detailed information quickly over long distances" (Riskus 2007). As more and more companies start using BIM as the built asset designing and modelling standard, other companies will be forced to follow, to keep a competitive advantage and to remain interesting as partners for larger firms that require their sub-contractors to use BIM as well.

Pragmatically, the number of firms using BIM is quite low, and this may have to do with the adoption cycle of any new technology. Moore (1999) provides a useful insight into this by arguing that there is a gap between the early adopters of a new technology and the adoption by the majority of the field. It is in this gap that many innovations fail or falter.

Figure 1: Technology Adoption Life Cycle - adapted from Moore (1999)



Another way of viewing this adoption gap, is what Kiviniemi et al. (2008 p.56) call the basic dilemma of BIM:

> The basic dilemma in the deployment of integrate BIM can be described as a paradoxical loop: there is not enough market demand for integrated BIM, because there is not enough measured evidence of benefits of the integrated BIM, because there are no adequate software tools to use integrated BIM in real projects.

Some pressure is needed to pull a technology from the promising early start to wide spread adoption by the majority of professionals. Enhancing client demand for the benefits provided by BIM is one catalyst for the adoption of the technology by most of the AEC/FM industry, and government is a significant client to that industry. For this to occur, governments would need to be convinced of the benefits of BIM, and ensured that all risks had been satisfactorily addressed. Appendix A contains a summary of projects which have demonstrated the benefits of BIM. Appendix B lists many of the tools developed by the CRC for Construction Innovation in the BIM area.

Summary of enablers of BIM

In summary, BIM as a suite of technologies has been enabled by the significant improvements in IT infrastructure, the capabilities of computer hardware and software, the increasing adoption of BIM, and the development of IFC which facilitate the sharing of information between firms.

To leave the discussion of BIM to just the benefits and enablers of BIM would leave and incomplete and inaccurate perspective on what the technology and organisations who manage them are capable of delivering to date.

In current practice, BIM is a hybrid, with several differing approaches being used. Each approach seeks to tighten integration, but the single universal model and perfect interoperability are still aspirations, not achievements (Ashcraft 2006). It is likely that the full capability of BIM will not be able to be demonstrated until these barriers and implementations are clearly understood and addressed.

Government, for its part, can enable the adoption of BIM through the use of BIM in various demonstrator projects and supporting the development and adoption of interoperability standards which are necessary precursors to the wider spread utilisation of the technology.

Section 3 begins this discussion be examining the disadvantages and barriers to implementing BIM. These will need to be addressed before wider spread adoption of BIM occurs. Section 4 advances ways in which these can be addressed.

3. DISADVANTAGES AND BARRIERS TO IMPLEMENTING BIM

If properly implemented, BIM has clearly some advantages and benefits for the AEC/FM industry. However, these advantages are not without some challenges. The technology and business process, upon which BIM is based, does have some disadvantages which are addressed in Section 3.1. Additionally there are some barriers to be overcome before the full potential of BIM is realised for the AEC/FM industry. In Section 3.2 an extended overview of these disadvantages of BIM will be given. Just as with benefits and enablers, government policy has a role in the mitigation of the barriers and disadvantages of BIM implementation.

It is important to note that while BIM is applicable to all stages of construction, Hartman and Fischer (2008) note that no single project to date has used BIM in every single phase of construction. Consequently, one of the main hurdles which needs to be overcome is the integration of BIM across all construction phases and by the different participants in a construction project (Hartman and Fischer 2008 p.3).

3.1 Challenges of BIM for AEC/FM industry

Just as there are a number of advantages to the use of BIM in the AEC/FM industry, there are a number of challenges. Those discussed here are the single model, interoperability, added work for the designer, and the sheer size and complexity of BIM. Need a sentence re policy/regulation

3.1.1 A single detailed model

Some authors (e.g. Batcheler and Howell 2005) argue that while the use of one single detailed model prevents errors arising from mixing up older and newer versions of a plan, a single model means that users cannot explore alternative designs. Designing is usually an iterative process that makes use of several different designs at the beginning to see which is best. Batcheler and Howell (2005) argue that this iterative process can get caught up in, or lost, in fast-track project schedules, and 'what if' scenarios for engineering design becomes more complicated by using only a single detailed BIM.

Discussions with users of BIM in Australia contest this point, arguing that BIM enables multiple design options to be explored, in more detail, with greater analytical precision, enhanced computation, and accurate feedback. In short, users of BIM argue that it provides better performing buildings, built more efficiently, with enhanced sustainability. In relation to 'what if' scenarios, again BIM users have contested this point arguing that BIM modelling allows for successive re-iterations of the building allowing for revisions to be made more quickly and cheaply, than with other approaches.

There is an implication of BIM for procurement – particularly the collaborative development of detailed designs. Government may need to consider which projects are best suited to the collaborative model building involved in BIM projects, as some will be more suited to this than others (particularly design-build and alliances).

3.1.2 Interoperability

The immense inter-organisational co-operation needed for BIM to succeed, requires a flexible technology structure that is both secure and provides easy access to users. It also needs to be scalable for high-volume operations as well as being cost-effective while doing so (Salazar et al. 2006). For this structure it is a practical concern that both contractors and designers have to implement 3D CAD and there is the need for all the firms in the industry to work with the same software, or at least the same standards (Taylor and Levitt 2007). However many project teams comprised have usually already optimised their work processes and use pre-existing technology already deployed in house. Besides based on the specific project requirements, it might happen that firms use different applications from different vendors for different projects, as they rely on the best-class application specified to the project (Batcheler and Howell 2005).

> In addition to addressing organizational interfaces, both design and construction firms must address the interoperability of technology at the technological interface between their firms. In other words, in order to co-create a virtual model, the 3D CAD software in both firms must be capable of opening and editing the electronic BIM … However, for the network to accrue the benefits of this additional work, the virtual

model must be used by firms downstream in the process. If one of the partners fails to adjust and utilize the extra work performed by the designer, then 3D CAD implementation fails (Taylor and Levitt 2007).

Kiviniemi et al. (2008 p.3) argue that IFCs are only a start, and in fact three different technical specifications are in fact needed. These include (capitalised words are in the original) an exchange format, defining HOW to share the information; a reference library, to define WHAT information we are sharing; and information requirements, defining WHICH information to share WHEN. Kiviniemi et al. (2008 p.3). In Australia buildingSMART has undertaken considerable work to ensure that these specifications have been developed. They include:

Technical specification	Kivimini et al. comments	buildingSMART specifications
An exchange format, defining HOW to share the information	Industry Foundation Classes	IFC (ISOPAS 16739)
A reference library, to define WHAT information we are sharing.	The IFD Library	IFD (ISO 12006-3:2007)
Information requirements, defining WHICH information to share WHEN	The IDM approach	IDM (ISO/DIS 29481-1)

As a regulator, government has a key role in ensuring the development of each of these standards. Ideally multiple governments would collaborative to development international standards which are then adopted in each jurisdiction in policy or regulatory instruments. As the development of these three standards is necessary to advance BIM and enable interoperability to succeed, government policy would need to be in place to facilitate the development and adoption of these standards across industry.

Thus the clear policy issues revolve around government involvement in the development of these standards and the adoption of these standards into policy and regulative instruments which would facilitate their adoption in industry.

The quotes above demonstrate that all the participants of the project need to switch to the same programs or implement the same IFC standards for BIM to succeed. If different organisations use different software or different versions of the same software - this can cause file incompatibility or corruption. This in turn will delay the project and require the firms to change software, with all the resulting financial implications. "The commonly held assumption why built asset design, engineering and construction have not utilized knowledge-based built asset models is due to fragmentation" (Eastman, Lee and Sacks 2003 ,). Each firm carries out only a few steps of the complex process and therefore has only the specialised software for those steps. In the end, inconsistent adoption patterns will result in financial problems for the firms involved (London and Bavinton 2006).

In the same line of reasoning, there is a need to obtain standardised software with the maintenance and decommissioning managers as well. A failure to gain cooperation from these users of BIM in the future, i.e. addition of maintenance data to the model, reduces the positive effects of BIM on these phases. If BIM is not kept up to date by a maintenance firm in a contract, the following maintenance manager will need more work to ensure the database is up to date. Likewise an incomplete BIM will mean that BIM will not be used in the decommissioning process, as out-of-date data is not safe to work with.

The development of IFC classes by buildngSMART goes a long way to solving this challenge, but as yet not all software vendors have adopted the standards. Government could therefore play a key role firstly in the development of these standards, and secondly the adoption of these standards into policy and possible regulatory instruments. Without leadership from government, the possibility exists for multiple standards to be developed which do not provide the necessary platform for development of the potential of BIM.

3.1.3 Added work for the designer

Another challenge of BIM is that the technology makes the drawing process fundamentally different. The designer will have to spend more time creating the initial drawing (model). This can be justified by the downstream benefits associated with information 'richness' and ease of modification, and many other users will be able to elicit information from the drawing. However, the designer's role becomes much more than simply communicating information about the overall look and design of the building to the engineers in the next stage in the process, as the drawing must instead form the foundations of a complete system analysis (Finch 2000). This does not only mean that the designer will have to perform more work, but alongside this new distribution of work and developing standards for interaction, both design and construction firms need to develop a system understanding of each others design and construction process (Taylor and Levitt 2007).

Pragmatically larger firms which employ architects, a variety of engineers, together with constructors and FM managers are the ones likely to derive immediate benefits from the technology, as additional effort in the design phase results in reduced effort in the construction phase.

For smaller firms, the additional work for the designer or architect of the model will need to be rewarded because otherwise the benefits only go to the end users of the model, and designers may be reluctant to perform the extra work and pay the costs for learning to use BIM software. Provided there was a long term benefit, i.e. better models were demonstrated as delivering reduced construction times or costs, initial investment in better models may be worthwhile. Incentives need to be provided to designers in order to reduce fragmentation in the industry and promote the adoption of new technology and ways of working.

There is an implication for procurement policy here which may need to consider additional funding needed for the development of BIM models by designers in the first instance.

3.1.4 The size and complexity of BIM

Batcheler and Howell (2005) argue succinctly, "one of the major drawbacks to BIM is the size and complexity of the files that BIM models create". As BIM requires a detailed visual model linked to a highly detailed, relational database, the scalability and manageability of a BIM model represents a major technological and organisational challenge. Currently, partial models cannot be exchanged, requiring entire models to be shared (Kiviniemi et al. 2008). Earlier users of BIM tended to default back to exchanging documents rather than working from a single model, which goes against what BIM is seeking to achieve in the first place (Batcheler and Howell 2005).

The large size of BIM files will require different means of data sharing. Real time access to the database from geographically distant firms, will require large and high speed broadband internet access, available at all times. "Synchronisation issues, project management, partial model exchange and software interfaces" (Kiviniemi et al. 2008 p.64) all require further research. The potential for data corruption, sabotage, and loss requires significant attention is paid to data stability and security for firms.

There are a number of public policy issues around data security, and infrastructure support for large BIM models – with both policy and technological frameworks necessary to support the size and complexity of BIM.

3.1.5 Trade Practices Implications

While BIM has been mandated in other countries, the Trade Practice Act prohibits action which might limit trade. Careful investigation should be made into the implications for trade, if only certain professionals were able to supply professional services to government, because they happened to have access to certain technology.

3.1.6 Summary of BIM challenges

As discussed in the foregoing section, BIM has some disadvantages. These disadvantages are mostly identified in the design and construction phase of the built asset life-cycle. These disadvantages mainly have to do with the differences in which architects and engineers work. Although all benefits are applicable for the design and construction phase, the maintenance and decommissioning phase benefit most from the increased speed and utility, better data quality and the visualisation of the data. In Table 2 these benefits have been summarised:

Table 3: The disadvantages of Built asset Information Modelling

Disadvantages of BIM	Description

A single detailed model	BIM does not allow alternative design options or the managing of 'what if' scenarios.
Interoperability	One software standard needed. Often firms have their own software, for BIM, every firm needs to change to the same software standard throughout the entire built asset process.
Added work for the designer	For BIM to work 'optima forma', the designer needs to create the 'rich' model. They will be drawing something that will form the foundations of a complete system analysis. This means a lot more work for the designer.
The size and complexity of BIM	The large size of BIM will require different means of data sharing, real time access into the database will require broadband internet access, together with security of data being worked on.
Trade Practices Implications	While some countries have mandated BIM, this is unlikely to occur in Australia, if this restricted trade.

3.1.7 Addressing the challenges

The challenges as set out in the previous section need to be addressed when BIM is desired to be implemented. Addressing these points will increase its strength and output. In this section some suggestions to mitigate the disadvantages are discussed.

A single detailed model

Even though BIM is a single detailed model, this should not limit the possibilities of experimenting with different versions in the design phase. In this phase, if desired, two or more initial models could be initiated, giving the designer room to experiment with alternative design schemes. This is assumed to take up a lot of storage space, but as the design progresses, in time only one design will remain. Together with the latest advances in IT technology, which allows for increasing storage capacity this disadvantage could become less challenging.

Interoperability

As it is vital for the success of BIM that all participating parties of the project use the same programs, the same versions of programs, and IFC standards, and this will have to be accomplished before starting the project. In the initiation stage all participants will have to agree on switching to the new standard if they aren't using these yet. Another option would to be only entering arrangements with partners that comply with the requirements on before hand. In this way interoperability challenges are addressed, as incompatibilities leading to delays can be avoided.

Added work for the designer

Certain incentives for the designers and architects of the model will have to be integrated in the contracting process, as the initial creators of the model, the designers and architects have a big influence on the future development of the model. The initial design stage therefore carries extra responsibilities, liabilities, and work. Straightforward rewards in money can be offered to the designer to compensate them for the work, or certain arrangements like royalties for artists could be incorporated when the underlying data of the model is used again. However these are just suggestions and have as such not yet been researched whether this is possible or legally achievable. It is however clear that the job description of the architect changes in BIM processes. Some of the issues which need to be resolved for this to happen – particularly IP, are discussed further in the next section.

The size and complexity of BIM

As addressed earlier, developments in internet and computer technology have greatly enabled the possibilities of larger and more complex technological projects. In general just the storage of the model should not create the largest of problems as storage space becomes increasingly cheaper. The larger difficulties will arise in creating real-time access and sharing of the database, ubiquitous high speed broadband internet is essential, together with ways of ensuring the data is secure, stable, and accessible. The key here is generating and/or accessing the right data for the right purpose rather than accessing all the data.

3.2 Barriers to BIM

The implementation of ICT technology in an organisation poses challenges that need to be overcome. In general these barriers can be technological in nature, but they can also be related to the need for organisational changes or changes to business processes or even just the speed of implementation (Burgess, Furneaux, Vassilev, Allan and Ward 2007). While BIM may contribute a lot of benefits to the construction process, the implementation of this technology presents numerous challengers which need to be overcome.

In the very traditional built asset industry, consisting of the Architectural, Engineering and Construction (AEC/FM industry), new technologies are not easily introduced. In general when a new technology is introduced, there is a certain period of time in which the claims about the potential of the technology need to be examined, tested and verified. Particularly the AEC/FM industry is known for the very long adoption periods of promising technologies, despite the highly mobile workforce that must collaborate with a range of on and off-site personnel, and make use of large volumes of information (May et al. 2005; Salazar et al. 2006). Even while new standards are being, and have been, developed (IFCs), the adoption of these standards has been slow. Due to this slow speed of adoption, it is very difficult to demonstrate the benefits of these standards (CURT 2004). In this section an overview of the barriers to the implementation of BIM will be given.

3.2.1 Raft of legal issues – IP, liability and risk, contractual forms

The first barrier is addressing the legal issues involved with BIM and the inter-organisational way of operating, using one single complex project file. In relation to BIM, the legal concerns identified to date include:

> risk allocation, standard of care, privacy and third party reliance, economic loss doctrine, who is the designer, intellectual property, etc. (Ashcraft 2006).

These concerns are grouped together and in this section the IP, Liability and risk, and contractual issues are treated.

<u>Intellectual Property (IP)</u>

As BIM typically involves architects and engineers in the creation of the model – together these individuals take responsibly for the creation of the 'rich' model that will be used throughout the process. This raises issues of who owns the Intellectual Property of the model. With 2D models, the copyright and related IP for a drawing is clear as this is asserted on each page of the drawings. However, in a 3D or 4D model, numerous professionals all contribute their expertise and IP in the development of the single model. An issue that needs to be addressed is whether a distinction can be made between the overall model, and the elements of which the model is comprised.

These IP difficulties compound over time. Imagine that a client contracts forms to deliver a large number of BIM models. Over time, government or any large client can pool the information in multiple models and therefore develop a large database of building elements, which is a valuable commodity in their own right. Will the architect or engineer be paid royalties every time the original element is used, or will he receive a one time sum of money at the outset? Will engineers be able to license various components of the building for use, or are they 'purchased' by the client? Frazer appraised some of the difficulties (and opportunities) that BIM offers architects:

> In my version of the story the architect sells seeds for whole generic built asset concepts and then leaves the computer, the environment, the user and the client to produce the one-off instances. The trick is to copyright (or, better still, patent) the genetic information in the seed. This will allow small

> architectural firms to vastly improve the quality of the environment, become very rich and spend a great deal more time on the beach (Frazer 2006).

One of the corollaries of this challenge is the fact that BIM operates on a large shared database. As work progresses, data is added and experience is gained. If all of this IP data remains within a singe architects office, the advantage of having a shared database quickly diminishes. To prevent this from happening, a secure environment for full collaboration is needed. "All users must be confident that their ideas and intellectual property remains well-maintained and secure, and that neither is compromised in the process of digital collaboration" (Bentley and Workman 2003).

This is also recognised by Drogemuller et al. who argue:

> The main issue that needs to be considered when assessing the advantages and disadvantages of each [project database] is the privacy of the information and the level of trust placed in the database administrator. A subsidiary issue is the capability of companies within the AEC-FM industry to manage shared data and databases (Drogemuller, Hampson and Yum 2003).

Further:

> The shared database model is acceptable for the common and shared information but trusting a database administrator with all of the intellectual property used throughout a project is potentially dangerous (Drogemuller, Hampson and Yum 2003).

As with other examples, the development of a large database only becomes problematic if what is involved is the collaboration of disparate firms. Large firms which employ architects and engineers on projects would assert the IP ownership rests with the firm, not the individual. Over time the library of building elements developed by such firms would be a source of competitive advantage against smaller firms.

In short, a series of solid and secure legal and technological frameworks need to be created to protect IP and prevent information from leaking to third parties, but at the same time preventing the original designer, the architect of the model, from becoming too powerful, and deriving long term financial benefits from the IP of other people, unless this is a preferred policy outcome of government.

Government will need to address the IP issues around the implementation of BIM – particularly who owns the data in the models. Such matters are likely to be needed to be addressed in both regulatory and contractual levels.

Liability and risk

A second challenge for using BIM is the question of liability and risk. If the process is simply that of the architect creating the seeds for the whole generic BIM concept and then leaving the rest up to others, as Frazer (2006) suggests, it is possible that the architect could be held responsible and accountable for any defects that occur in the model. In the past this has resulted in self-protective behaviour from the architect:

> "Due to reluctance on the part of the architect to share their models out of liability concerns, some innovative general contractors began developing their own construction phase models" (Batcheler and Howell 2005).

When in a later stage the model turns out to be faulty, the engineers and constructors will most certainly shift the blame to the original creator of the work. "This creates the anomaly that the designer that initially creates the model receives little immediate benefit, but subjects itself to increased potential liability" (Ashcraft 2006).

In current practice it is the contractors and engineers who are responsible for fault in constructions, however "with the co-creation of a virtual model boundary object, it is no longer feasible to create designs that are not to scale. If a dimension in a virtual model is imprecise and an element does not connect to a built asset properly during construction, then a contractor can claim that this is the fault of the designer" (Taylor and Levitt 2007). One of the contractors described his concern over liability as follows; "if we get a (3D CAD) model from an architect there may be mistakes since the architect doesn't guarantee that the model is correct" (Taylor and Levitt 2007). Consequently, some contractors even redesign the model themselves.

These liability tensions will tend to slow down BIM adoption. "Unless commercial and legal structures are modified to rebalance the compensation, risk, and reward, BIM cannot achieve its potential" (Ashcraft 2006). However Ashcraft also identified that; "On complex projects, conflict identification and resolution is an extraordinarily expensive and difficult task. In many instances, designers do not have the time or budget to fully explore and resolve conflict issues" (Ashcraft 2006).

Pragmatically these issues need to be sorted out before project commencement, or the project will fail even before it has started. Networks that have successfully implemented 3D CAD systems, have addressed redistribution of work by addressing liability and addressing contractual constraints. In Taylor's study this was particularly important for designers whose scope of work was being increased by the redistribution of work (Taylor and Levitt 2007).

Contractual

The issues of IP and liability and risk influence mean that contractual relations between parties in the built asset industry will need to address these concerns. "Contracts must address the risk associated with the data developed in BIM design as it relates to the different parties participating in its development; re-use of the data developed in BIM design also needs to be clearly articulated" (CURT 2006). Ashcraft formulates the same thought by saying that deep collaboration promises can greatly increase efficiency and quality. But they will be hollow promises unless the commercial and legal structures used embrace new approaches to compensation, responsibility and risk. "These new approaches will have to be developed to support the collaborative processes within a structure that maintains design integrity and discipline" (Ashcraft 2006). Put simply, "BIM will have impact on contractual and process issues in the AEC/FM industry" (Kiviniemi et al. 2008 p.80).

In current practices where BIM has been taken into account while making the contracts, Taylor has found that "In some cases the virtual model co-created by the designers and the contractors became a component of the contract. One designer described the virtual model becoming part of the contract document" (Taylor and Levitt 2007). This may be a logical extension of the current practice of attaching 2D drawings to plans and making these an addendum or schedule to the contract. It is possible that such processes would require public policy or even legislative changes in order to have effect. It is clear however, that contracts structure will have to deal with, and clarify, IP issues, risk and liability, protection and ownership of data used in BIM. How exactly these requirements for the new contracting structure are to be applied is however still subject of investigation.

Clearly the matter of risk needs to be addressed at a policy level and at a contractual level – particularly in procurement, although there may be a need to address this at a regulatory level if the scope of adoption became quite extensive.

3.2.2 Authenticity of content authors

The second barrier addressed in this section is the issue of authenticity of users when using electronic media to share information. These security issues are large within a BIM environment where the simultaneous electronic sharing of the data is perceived as one of the main benefits of BIM. This situation is exemplified for electronic tenders: "given the ease with which documents and identity can be manipulated in an electronic environment, it is necessary to employ a tendering system that minimises the potential for a person to submit a tender without the appropriate authority or for a person to forge a tender adopting another person's identity" (Betts et al. 2005). While applying this to electronic tender documents, this could equally apply to BIM documents, particularly if the internet is used to collaborate on specific projects.

The situation of multiple users working on a single database remotely, and collaboratively developing a 3D model of a building may result in inadvertent design flaws. The building may be subsequently built to specification; however, through the faulty design major re-work was required. It is unclear who would be responsible for faulty design if multiple people were able to modify certain building elements. For example, care would need to be taken to ensure that the electrical engineer does not alter the mechanical engineer's specifications, nor should an architect be able to modify the work of the structural engineer, nor the constructor of the designers. The issue of authentication and tracking of changes made by users is a non-trivial one which goes to the heart of being able to collaborate and share information in a single model. Although one of the issues with paper drawings is that builders change the design and little or no record is kept of these changes

This problem is also recognised in a recent eGovernment report which notes states that “major security issues surround authentication of users and securing the integrity of messages and data, confidentiality and privacy associated with the transmission of information” (Burgess et al. 2007). Even though the use of online systems tends to be more efficient and cost-effective, the shift to an electronic environment presents several legal hurdles, in part “because the law that governs electronic transactions is under-developed and lags behind the technology” (Betts et al. 2005).

The difficulty is also likely to have a negative effect on adoption of BIM. The perception of IT environments as insecure is a commonly held assumption prevalent throughout the construction industry and is a key problem: “perceptions of IT as an insecure environment have insinuated itself [sic] into lower levels of organisational trust, in which firms deploy stringent intranet security measures designed to protect sensitive information and presumably defend against loss of commercial advantage via leakage of sensitive information” (London and Bavinton 2006).

Betts also suggests a possible solution to the authenticity problem by suggesting that authentication and non-repudiation can be achieved using digital signatures: “Digital signatures provide a high degree of assurances as to the authorship of digital data which could be used in a legal dispute” (Betts et al. 2005). As with other barriers noted above, many of the current firms using BIM are firms which have their own in-house architects and engineers, so the issues of authentication can be addressed and tracked in house. It is the collaboration across firms which presents as a distinct challenge.

The process by which BIM enables the authentication of users is one that requires careful consideration and planning in the coming years, and may need modifications not just at a technological level, but also at a contractual, policy and legislative level as well. Given that 93% of the construction industry is comprised of SMEs (London and Bavinton 2006) this is a significant area which needs to be addressed before wide spread adoption of BIM technology is likely to occur.

3.2.3 Costs

The third barrier is a result of a combination of two challenges from BIM. The interoperability and added work for the designer both result in perceived additional costs. As stated earlier, for designers the economic advantages of BIM are less immediately tangible. Unless the designer shares in the economic benefits, the owner, and builder not the designer, reaps the immediate benefits. Yet as noted earlier, there are also significant benefits for the construction phase, if all the design issues (e.g. clash detection, and coordination) are resolved. Yet it is the designer, not the owner or builder that must adopt and invest in the new technology at the outset (Ashcraft 2006).

While architects were initially expected to adopt BIM, they have not done so on a large scale to date (Eastman, Lee and Sacks 2003). The development of a construction level 3D model, with fully attributed objects, involves significantly more information than is currently required in drawings provided by the designer. “While design activities have a large value-added component, architects and engineers receive a small and relatively fixed percentage of the construction dollar. No effective business plan has been implemented to pay for the additional work that populating a built asset model would require” (Eastman, Sacks and Lee 2002). Part of the issue is that because no one party to the built asset process in particular seems to benefit from the switch to BIM, but since the process as a whole improves, it is argued that the owners and clients of built assets are the beneficiaries and should financially support this transition.

As a result of the perceived extra costs for the designers, especially small firms, many will be hesitant to start using BIM. The initial expenses associated with acquiring the software and investing time and personal in understanding the software may be considered to big a risk for small firms and they may want to be waiting to see if one dominant software provider emerges, to avoid purchasing a software program that may be obsolete in a few years (Riskus 2007).

As another issue, because the implementation of BIM is supported by the exchange of data between software tools to speed up analysis cycle times and reduce data input and transfer errors, their set-up, testing, and use cannot typically be financed on a single project basis. This means that the implementation of such an innovation needs corporate or government funding. Once the program is adopted and effectively in use and when a wealth of information is obtained and users have learned how to reuse project data to do future work with a smaller budget. This can "provide a competitive advantage that is more sustainable than that gained from just having visual models" (Fischer and Kunz 2004).

However this viewpoint needs to be relayed to the industry and be accepted and adopted to overcome the initial barrier of high costs. It also introduces the possibility of extra costs due to licensing of expertise. When information is reused, who safeguards the IP of this information? This information will most likely be protected by copyright and therefore has to be bought or licenses have to be obtained to be allowed to reuse this information.

A final issue comes from opportunity costs. As BIM is based on a single model, to which all users have access, extra costs can arise due to sabotage, neglect or errors. Thought also has to be given to the powerful positions some firms might obtain during the designing process, which could lead to opportunistic behaviour. For example large design firms could exact a long term rents from the development of highly detailed databases of building assets.

Government may be able to address many of these issues, by insisting on the ownership of the IP, and rewarding or requiring the adoption of BIM for government projects. A proper cost-benefit analysis would need to be undertaken for such a decision to be considered however. There are direct costs for industry and for government in the purchase of advanced hardware and software to implement BIM, together with indirect costs associated with increasing storage capacity, security, and training in the use of this technology. There are also opportunity costs associated with the rich data model which needs to be addressed in contractual and possible legal frameworks.

3.2.4 Socio-technical issues

The fourth barrier is the set of socio-technical issues related to the introduction of BIM. In his 2005 study of the adoption of 3D CAD, Harty (2005) suggests that social and organizational contexts need to be taken into consideration to understand the adoption of this technology. This is also recognised by Taylor and Levitt (2007) who claim that "though the researchers have explored the issues associated with inter-organizational information system boundary objects in networks, there is little in the way of guidance on how a network of firms would go about implementing technological changes of this kind" (Taylor and Levitt 2007). Even a cursory review of BIM literature, the implicit, and sometime explicit, expectation is that BIM would automatically be adopted once available (Batcheler and Howell 2005). However, such an adoption has not happened and will not happen automatically.

BIM requires more than technological and legal enablers. BIM is most likely to require a large range of changes to the way AEC/FM firms relate to each other and interact. As Baker et al. state the process of technology adoption begins from "the premise that interoperability endeavours come along with – as they both require and provoke – organizational and inter-organizational arrangements. These bring several challenges such as new attitudes toward information, the re-distribution of power structures, new organizational forms, re-definition of terms and territories. Before being materialized in technical artefacts and organizational structures, interoperability strategies first develop in the interplay of negotiations" (Baker et al 2005).

Just BIM in itself does not drive this change, but is in itself an enabler of this institutional process. "It is people that start organisational changes" (Spitzer 1996). Therefore, "selection of project personnel will remain an important component of built asset project implementation, as well as the interactions and clarity of communications between stakeholders" (Ellis 2006). The socio-technical view suggests the need to focus on people, alongside technical and institutional components, in the definition and design of BIM initiatives. "Based on this view, a shift is suggested from a techno-centric position to a socio-technical position within a spatial data community" (Rajabifard and Williamson 2003). Just as people shape technology, technology can shape jobs, roles and organisations.

However, in order to perform this shift in the built asset sector, significantly more work needs to be done to ensure that BIM fulfils its promise. As Burgess et al (2007) found, in the end, adoption of technology requires organisational and business process changes as well as technological development. Successful implementation requires more than the appropriate IT platform and assuming that the technology will drive the change, people etc, (Burgess et al. 2007). To date, much of the work on BIM has focussed on addressing the technical issues involved in creating a viable product, and now the inter-organisational issues must also be addressed.

3.2.5 Skill issues

The last barrier addressed in this section will be the skill issues. This barrier relates to the required operating knowledge that is inevitably accompanying any purchase and integration of a new IT application, such as BIM, into a business process. Associated with the need for training is the consequent loss of productivity that goes along with it. This incurs a double cost for the company. Not only are companies paying for the re-education of their employees, but also they loose money due to a decrease in productivity. For that reason, "Staff training is evaluated as an additional (and negative) cost associated with IT outlay" (London and Bavinton 2006)

Next to that, is the notion that most of the software used in the AEC/FM industry, has a shared characteristic. The proper use of these programs requires "intricate knowledge of the application and expertise in the corresponding industry discipline" (Bazjanac 2004). The process to obtain a high level of knowledge and expertise of this software is often very difficult and often prohibitively expensive (Bazjanac 2004). Without sufficient training or guidance, access to BIM may be limited or inhibited by users either not having the capability or the know how in terms of connecting to the system (Burgess, Furneaux and Vassilev 2007) as "firms were only able to successfully implement 3D CAD after they were able to obtain sufficient training" (Taylor and Levitt 2007). It is therefore, that the introduction of BIM in the AEC/FM industry will be difficult to realise. Either sufficient trained personal will have to be recruited or existing personal will have to be trained to an appropriate level. This will again incur more costs for the industry.

Government may be able to facilitate the up-skilling of the industry by building capability over successive projects. For example, schools and hospitals may have similarities, or even standardised buildings, or building elements, which could be used in ongoing programs of work. Staged migration to BIM could also assist with professionals using BIM in their own disciplines in order to develop skills, and then to collaborate with other professionals. It would appear that implementing BIM does require addressing skills at these two levels – mastery of the technology itself, and then developing the skills to work in a cross-disciplinary, and collaborative manner with other professions.

3.2.6 Summary of challenges

The foregoing section has dealt with several barriers of implementation for BIM. To give a short overview of all the barriers, Table 4 gives a summary of these barriers.

Table 4: The barriers to the implementation of Built asset Information Modelling

Barriers of implementation	Description
Issues concerning; IP, liability, risks and contracts	As the designer is responsibly for the creation of the 'rich' model that will be used throughout the process, this raises issues of who owns the IP, who is liable, what are the risks involved and how will new contracts be structured?
Issues concerning the authenticity of users	Using electronic environments for tendering, raises authenticity questions because manipulation of data may be possible and the authenticity of users needs to be secured.

Barriers of implementation	Description
Costs	For designers the economic advantages of BIM are less tangible. Yet it is the designer, not the owner that must adopt and invest in the new technology, So unless the designer shares in the economic benefits, the owner, not the designer, reaps the immediate benefits and the designer pays the price. Builders and owners benefit significantly from BIM.
Socio-technical issues	Attention needs to be given to the socio-technical issues which arise from implementation of new technology which results in new ways of doing business
Skill issues	Access to BIM may be limited or inhibited by users either not having the capability or the 'know how' in terms of connecting to the system. Obtaining sufficient level of knowledge and expertise that is required for BIM may be difficult and prohibitively expensive.

In the previous sections, not only the technical limitations of BIM have been identified, but so too have the legal, social and financial barriers that can prevent a successful implementation of BIM. For the further development of BIM, new business models will have to be designed that assist the integration of BIM as a project delivery method, rather then the old methods were it is attempted to integrate this new technologies into conventional practices (Ashcraft 2006).

> "This rethinking must necessarily include a disavowal of the "build it and they will use it" mentality that infiltrates much of web-enabled thinking" (Davidson 2005)

Given the potential of BIM as a set of technologies, it is certainly time to address the numerous financial, intellectual, legal and organisational issues which currently inhibit the widespread adoption of BIM. As has been outlined above, it is likely that a range of policy instruments would be required to address all of these concerns – policy and regulation, financial support allowances and incentives, education and the trialling of the technology in numerous settings.

4. CONCLUSIONS AND RECOMMENDATIONS

This report outlines the current potential of BIM to enhance the productivity of the AEC/FM industry. The promise and advantages of an integrated information and database sharing model across the entire life span of a built asset have been identified, together with the current barriers to implementing such models on a large scale.

Many of the tools and technology that have been discussed in this report are embedded in daily work practices of AEC/FM professionals already. The main challenges are not the interconnection of software tools anymore, but rather establishing processes and best practices, overcoming the barriers, and managing the social element of socio-technical systems. Kajewski (2001) summed this up recently: "Research further indicates, one of the last available 'mechanisms' left for organisations to improve their competitive position within the AEC/FM industry is by considering its people (culture) along with its technology" (Kajewski, Tilley, Crawford, Remmers, Chen and Weippert 2001). In other words - it is not the technology itself that we should be focussing on anymore, but the process of interaction between architects, engineers, constructors and government.

Such interactions have implications for the types of procurement arrangements which would facilitate such interactions, together with the contractual, legal, financial, and technological frameworks needed to support the implementation of BIM and the amelioration of some of the difficulties associated with implementing BIM>

However, it was already noted by Williams and Dobson (1993); “changing the culture of an organisation and its members takes time. That is because it is a slow process for people in existing or newly established ‘social systems’ to develop a new set of common held beliefs, attitudes and values” (Williams and Dobson 1993). What this means for BIM, is that changing current ways of working will not make BIM an instant success. Many firms adopt ICT tools and systems for profit-motivated reasons, and often failing due to underestimating the social implications of the change brought by the innovation. “Successful ICT adoption depends on the ‘politics of technology’ in its management in the organisation” (Kajewski et al. 2001).

4.1.1 Recommendations

BIM does have significant potential for government. Government, as a significant client of construction has been called upon to be an early adopter of the technology (Kiviniemi et al. 2008). Pilots in various countries have demonstrated significant time, costs savings and quality enhancements. There are however significant barriers and costs which need to be addressed in order for these benefits to be realised on a broad scale. It is therefore recommended that several small and some larger pilot projects are undertaken first, in order to assess the benefits of the technology, and to work through the numerous issues raised in this paper. Additionally, these pilots could be conducted in different jurisdictions and for different clients, as such variables are likely to provide valuable lessons which have purchase in wider contexts.

In this regard it is important to note that the Office of the Chief Architect of the General Services Administration (GSA) in the United States of America has now mandated BIM models be provided on all future GSA building projects (Dakan 2006). Such a decision was not made on an ad hoc basis, but appears to have followed a period of testing the technology in a series of pilot projects (Kam 2008). It is unlikely however, that government would mandate BIM, due to the provisions of the Trade Practices Act, which would prohibit any action which might prohibit trade – including limiting supply to those organisations which have access to certain technology.

The CRC for Construction Innovation has completed a case study of the use of BIM in the Sydney Opera House, which was a significant success. See Appendix A for a brief overview of these and other projects (such as those conducted by the GSA) and a review of the case studies. Other case studies are currently underway.

The implementation of BIM has applicability for the entire life span of a built asset. Therefore it would be ideal if at least one, but preferably more, of these pilots are applied to new built assets, starting from the design phase, all the way through the final delivery of the built asset to the owner, to the facility management stage of the built asset. Reviewers of earlier drafts of this document suggested that a number of pilot projects could be identified:

- An existing building not using BIM, but create an FM capable BIM to assist in the operation and management of the building. Such a project is actually currently underway.

- That a long term building program, such as for schools, be implemented. Schools are likely to have similar buildings across a given state. Hospitals were also suggested as possibly being similar enough to undertake comparisons. By implementing BIM across multiple sites, a number of buildings can be compared with each other. Such a large adoption program may also facilitate the development of the capability of the industry by providing a steady program of work.

Given the numerous barriers identified above, a concurrent review of the inter-organisational, legal, public policy and financial issues inhibiting the implementation of BIM also needs to occur.

5. LIMITATIONS OF THE STUDY

This study is a wide-ranging review of existing research and findings with particular applications of the utility of BIM to government. To this end a pragmatic assessment of the costs and benefits, barriers and enablers of the technology for government has been undertaken, together with recommendations on how this might be improved. Obviously field based research would be required to validate the findings in this report, together with an investigation of ways in which the issues have been, or could be, addressed in detailed case studies. It is possible that published research may be lagging a couple of years behind practice.

6. APPENDIX A – APPLICATIONS OF BIM – EXAMPLES

6.1 *Application of BIM*

In previous sections, the advantages and enablers of BIM were discussed and it has been explained what BIM is. This section will show where BIM has been used and where it can be used.

After the discussion of these various projects that involve BIM, the second appendix will show specific BIM applications which are to being developed by the CRC for Construction Innovation. These involve the use of BIM for:

- Built asset cost estimator
- Automated Scheduler
- Built asset code checking
- Environmental Impact Assessment
- Road Asset Management Investment
- Mobile computing

6.1.1 Applications of BIM in the past and present

In literature several applications of BIM in the industry can be identified. One of the most recent applications within Australia has been the application of BIM to the Sydney Opera House as mentioned before. To demonstrate BIM's utility in Facility Management, the Australian government, the Cooperative Research Centre for Construction Innovation (*Construction Innovation*) and a number of industry participants and research organisations worked together on this Sydney Opera House project where digital modelling, services procurement and performance benchmarking were integrated together for the best possible Facility Management. This project, as well as other projects performed by various organisations shows the possibilities and advantages of BIM for the government sector. Table 5 gives an overview of all the identified projects that have implemented BIM, either as a subject of study, or as a tool. The most important ones will be discussed in the following section.

Table 5: Overview of applications of BIM in current and past projects

Project or Organisation:	Role of BIM within the project:
The Sydney Opera House (CRC 2007)	BIM as support for Integrated Facility Management.
The Construction Operations Building Information Exchange (COBIE) project (Fallon and Palmer 2007)	COBIE is creating a standardized content and format for information handover to operations and maintenance, as a part of the U.S. National BIM standard (NBIMS)
Public schools in Bourgogne (France) (US ACE 2007)	All the public schools of the region will progressively become available in IFC format (CADOLE project, funded by the Region as facility manager)
US General Services Administration (GSA) (US GSA 2006a)	The GSA has created its own 3D-4D BIM Program. Starting from 2007, the GSA has mandated the use of interoperability and IFC for all major projects. This followed a pilot study which tested BIM on 9 separate projects.
The US Pentagon Renovation and Construction Program (PENREN) (Dahl et al 2006)	The US PENREN Program uses the diagnostic Post-Occupancy Evaluation (POE) process which systematically evaluates the performance of built assets after they have been built and occupied for a length of time

Project or Organisation:	Role of BIM within the project:
The Airbus restaurant in France (IAI 2006)	Main Purpose: to populate the FM system with IFC files provided by the designers
The Freedom Tower in New York City. (Batcheler and Howell 2005)	When completed, the Freedom Tower will be 1,776 feet tall, the world's tallest built asset, and contain approximately 2.6 million square feet. Given the high visibility and aggressive schedule associated with such a large, complex project, SOM's commitment to a full BIM approach to the project is both a bold bet, and the only realistic way to deliver on the unique demands of this project
The UK Process Protocol model (Kagliodlou et al 2000)	Based on a 2D model, the process protocol adopts a normative approach to inspire companies to use a more disciplined strategy to project management
The model from the Finnish Construction Process (Karhu and Lahdenpera 1999)	The Technical Research Centre of Finland created a model that followed existing practice quite close, since the input consisted of checklists of tasks produced by the Built asset Information Institute, which are the 'de facto' standard in Finland
The IBPM of Pennsylvania State University (Sanvido et al. 1990)	The work carried out by the Pennsylvania State University has been a large influence on later work in formalised modelling technology. It was carried out with close collaboration with industry and real projects
The Dutch 'Bouw informatie model' (van Merendonk and van Dissel1989)	They used BIM in essence as a design process model, intended to serve as a framework for describing information in the creation and modelling of the model
Queensland State Archives, Runcorn	This is pilot project conducted by the Department of Public Works where a 3D model was developed from 2D drawings and used for the design and construct phase. The project is currently being evaluated. 4D construction scheduling was also a key element of this project.

Sydney Opera House

The Sydney Opera House is recognised throughout the world as an iconic symbol of Australia. As FM is considered an ideal tool for the "integration of disparate information management systems, firstly in order to better align FM performance objectives with the organisational objectives, and secondly to further FM objectives in terms of better and more effective FM practices and service delivery" (CRC 2007). In a response to this idea, the Sydney Opera House was used to conduct research on FM in practice, and with the objective of using the research to demonstrate FM as a business enabler and to provide insight into the need to develop a more generic integrated FM solution for the FM industry as a whole. The FM Exemplar Project combines three research streams dealing with Digital Modelling, Services Procurement and Benchmarking as a whole then develop collaboration between them. It aims to achieve innovative FM strategies and models that will showcase improved FM performance and promote best practices (Ballesty 2006; CRC for Construction Innovation 2007).

The results of the project as a whole, and the benefits for using BIM in the FM in general, encompass the following benefits as put forward by the project; The key benefit of digital modelling is its accurate geometrical representation of the parts of a built asset in an integrated data environment:

- Faster and more effective processes. Information is more easily shared and re-used
- Controlled whole-of-life costs and environmental data. Environmental performance is more predictable and lifecycle costs are understood

- Integration of planning and implementation processes. Government, industry and manufacturers have a common data protocol (CRC for Construction Innovation 2007)

Plans are underway to test the applicability of the technology in commercial buildings.

COBIE

"The Construction Operations Built asset Information Exchange (COBIE) builds upon earlier work. COBIE is a 'built assetSMART' initiative of the National Institute of Built asset Science's Facility Maintenance and Operations Committee, the Facility Information Council and International Alliance for Interoperability, and the National Built asset Information model Standard. It is a federal government (UA) sponsored effort to support the development of Built asset Information Model(s) (BIM) via information exchange between construction and operations phases" (Brodt, East and Kirby 2006).

"The Construction Operations Built asset Information Exchange (COBIE) project, with funding from the U.S. national Aeronautics and Space Administration (NASA), is creating standardized content and format for information handover to operations and maintenance as part of the U.S. National BIM standard (NBIMS). The COBIE approach envisions capturing this information incrementally throughout the facility planning, design and construction processes" (Fallon and Palmer 2007).

GSA BIM

In 2003, the US General Services Administration, which is responsible for the management of all civilian federal public built assets in the United States, created its own 3D-4D BIM Program, the National BIM Standard. Starting from 2007, the GSA has mandated the use of interoperability and IFC for all major projects (Kam and Hagan 2006, US GSA 2006a, US GSA 2006b). This followed a number of pilot projects where BIM was trialled. The various pilot cases are summarised below (Detailed review can be found at http://www.aia.org/SiteObjects/files/gsa.pdf):

1. 26 Federal Plaza, New York, NY
   - "An as-built laser scanned 3D model was compared to the 3D design model based on the architectural, structural and MEP (mechanical, electrical, plumbing) design, which identified a major error in a structural wall placement that was caught early enough in the project to save significant time and money" (Dakan 2006).

2. Office Building, Houston, TX
   - "BIM enabled early detection of design errors and omissions pertaining to an innovative façade system, avoiding costly change orders during construction" (Dakan 2006)

3. U.S. Courthouse, El Paso, TX 4. 300 NLA Federal Bldg, Los Angeles, CA
   - "3D spatial information model information was used to assess quantitative data about building efficiency, fenestration ration, volume ratio, usable floor area and other factors to ensure compliance with GSA design standards and ANSI-BOMA standards" (Dakan 2006)

4. 300 NLA Federal Building, Los Angeles, California:
   - "A fully occupied federal building was guided through a 16-phase seismic upgrade and renovation project by using 4D modelling to reduce the overall schedule by 19% and uncover major errors in cost assumptions and communicating extensive move operations for tenant agencies" (Dakan 2006).

5. Eisenhower Exec. Office Bldg, Washington, DC
   - "BIM and a QuickTime movie were created for a historic rehabilitation project involving new glazing to assess daylight and shadow studies and compliance with historic guidelines and building security" (Dakan 2006).

6. GSA Regional Office Building, Washington, DC
   - "4D modelling (3D plus the fourth dimension of time to reflect scheduling, construction sequence or phases) was used to analyse cost/time implications of different alternatives for a two-phase modernization project, which uncovered information discrepancies about existing tenant agency locations and sizes" (Dakan 2006)

7. GSA Central Office Building, Washington, DC

- "BIM and IFC (Industry Foundation Class) data enabled direct model exchange with a consultant for energy analysis of an existing office building using a DOE-2-based program to model energy use based on occupancy activities across a typical work day" (Dakan 2006).

8. Border Station Prototype, U.S.-Canada Border

- "Site orientation tradeoffs, structural system alternatives, vehicular flow, prefabrication construction studies and material choices were analysed from the early programming phase throughout the design process" (Dakan 2006).

9. U.S. Courthouse, Portland, OR

- "4D modelling integrates design intent, structural engineering and construction scheduling into one model to foster GSA communication to the public, tenants and contractors for a seismic upgrade, including base isolators for a historic landmark courthouse building" (Dakan 2006).

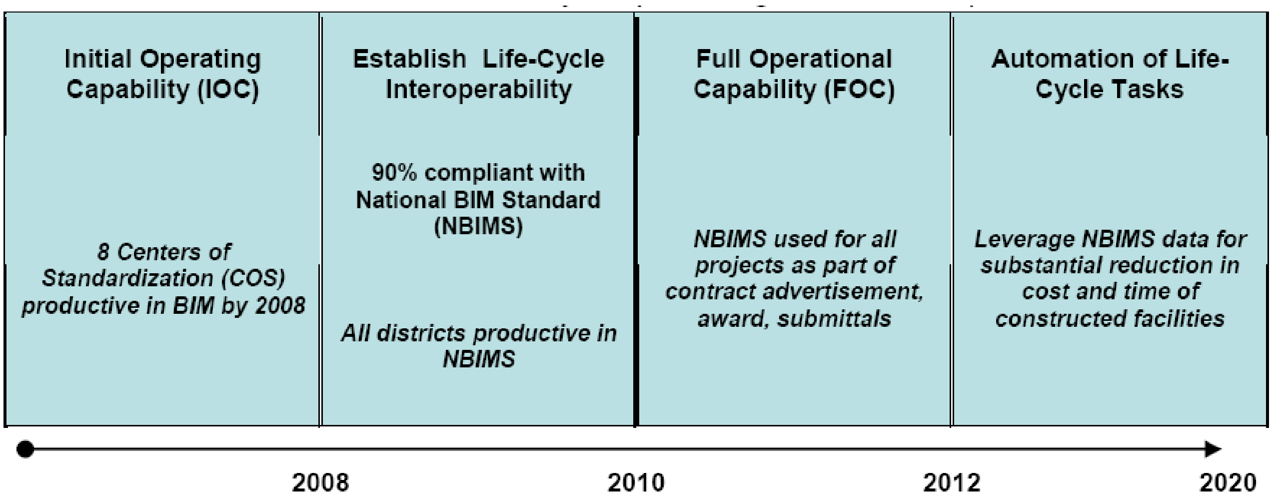
According to Matta et al. (2005) the direct benefits from these pilot studies include :

> optimize construction schedule (e.g., reduce duration by 19% in 300 NLA Federal Bldg), improve as-built documentation (e.g., 26 Federal Plaza), uncover design errors and omissions (e.g., uncover envelope and coordination omissions in Houston Federal Office), and improve the means for communications through 3D-4D BIMs (e.g., with tenant agencies and during pre-bidding conferences). Furthermore, GSA's initiative has led other federal agencies in the adoption of BIM and has made a major impact on the industry (people, culture, and process), on peer owners, on the attitude towards open standard, and on the importance of establishing an owner's BIM and its requirements.

US Army Corps of Engineers

The US Army has recognised the importance of BIM and through the US Army Corps of Engineers (US ACE) it is implementing BIM (US ACE 2006). By 2010 US ACE wants to have 90% compliance with the National BIM Standard (NBIMS) (US ACE 2006).

Figure 2: U.S. Army Corps of Engineers roadmap for the implementation of BIM (US ACE 2006)



US ACE actively participates in the development of open standards (NBIMS) for a number of reasons (US ACE 2007).

- Greater competition
- Non-restrictive contracts
- Government owns data in long-term format

What the American Department of Defence (DoD) wants to achieve it the implementation of BIM is a Common Output Level Standard (COLS) that has to provide a common language that is critical for the creation of Joint Base installations. The DoD expects to "significantly … reduce duplication of effort with resulting reduction of overall manpower and facilities requirements capable of generating savings" (BRAC 2005). The US ACE recognizes that BIM supports their Military Construction (MILCON) program, which covers the construction of facilities and structures as it benefits the design and construction. At the moment, under the Military Transformation program, BIM is a primary deliverable in the US ACE's 'FY08 RFP', the request for a project pre-proposal. The US ACE expects its design and construction contractors to develop BIM capabilities and their software vendors to use Industry Standards (e.g. NBIMS) and achieve interoperability (US ACE 2007).

At the moment the following US federal organisations are effectively implementing BIM, in addition to DoD:

- U.S. Coast Guard
- General Services Administration
- NASA
- Smithsonian Institute

7. Appendix B – BIM Software applications developed by the CRC for Construction Innovation

Due to the potential for BIM products to significantly improve productivity in the construction industry, a number of tools have been developed by the CRC for Construction Innovation. These software applications operate at a number of different stages of the construction process. A summary of their applicability is provided below followed by an outline of the tools themselves.

	Design	Construction	Operation	De-commissioning / Re-Life
LCA Design	X			
Design Check	X			
Automated Scheduler		X		
Automated Estimator	X	X		

Implications of BIM in the design phase for Government

The CRC for Construction Innovation has sought to capitalise on the capability of BIM modelling in the design phase of built assets. These new BIM applications have several indirect implications for government in the design phase. 'Design Check' has been designed to check a 'drawing' for compliance with the building code of Australia (BCA). LCA Design has been developed to asses the sustainability performance of the proposed building, through the BIM model. BIM thus has the potential to improve the speed at which buildings are assessed by local government authorities for compliance with the building code of Australia, together with local planning laws, although such technology is still in the early phases of development.

Both these tools allow governments to makes early decisions about their own projects, or monitor projects developed by private organisations. As governments of all persuasions are focussed on delivering buildings which comply with the BCA and achieve high levels of sustainability, the tools developed by the CRC for Construction Innovation can facilitate assessment of the sustainability performance of buildings prior to construction.

7.1.1 LCADesign

LCADesign stands for Life Cycle Analysis of Design. This program enables built asset designers to make an automated Eco-efficiency assessment of commercial built assets. It does this by providing detailed environmental assessment measures for different materials, products and designs, from the 3D BIM.

As built assets consume significant amounts of resources, both in their construction and operation, they remain an essential part of the world. The ability to assess their impact and to design alternatives to reduce that impact is the core purpose of LCADesign. With this program reductions can be realised in then use of water and other resources and it reduces de impact on air pollution and the amount of solid waste produced.

The benefits of this program are:

- Automated environmental assessment measures directly from 3D CAD drawings or BIM.
- Choice of environmental impact and performance measures
- Detailed design evaluation
- Comparative ratings of environmental impacts of alternative at all levels of design analysis
- Comprehensive graphical and tabular outputs
- Sustainability assessment

- Sustainable cities report tools
- Push to 5-star built assets

(Construction Innovation date)

7.1.2 Design Check

Checking the compliance of a given built asset with the Built asset Code of Australia can be a tedious task for architects and designers. *Construction Innovation* has developed an advanced computer software tool that provides automated checking of designs against the Built asset Code of Australia. When architects and designers uses the Design Check tool together with their BIM, this complex task becomes less error prone and less time consuming.

The design check tool uses the IFC information available in BIMs and checks this with the built asset regulations in its own database. This allows for automated code checking at various stages of the design. However at the moment only the disability code of Australia has been realised.

7.1.3 Automated Scheduler

Automated scheduler is a prototype computer software tool that automatically prepares construction schedules together with a 4D simulation of the construction process from a 3D CAD built asset model. (CRC 2005) author date

In the early developing stage of a project, different plans might be considered. These plans can differ in sequencing, timing and use of resources. Also during the construction higher level plans need to be defined at greater levels of detail within de constraints of the initial planning and the evolution of the project. The preparation of these plans using Gantt charts can take a long time. With this program the efficiency of this planning can be increased and lead times can be reduced.

Information contained in a BIM is exported as IFC data and used to populate a database. The program then uses this data, together with a set of knowledge rules, construction times and resources, to produce a simple built asset construction plan.

The plan can be shown in a 4D model that shows the various stages of the project from beginning to end. This visualisation of the process enhances understanding and issues identification especially with non-technical people.

The Automate Scheduler program is designed for a wide range of possible users. The program is beneficial for:

- Built asset contractors/subcontractors
- Architects/Designers
- Consultants
- Construction principals
- Academic/teaching institutions

(CRC AS 2005)

7.1.4 Automated Estimator

The Automated Estimator tool uses the IFC data available in a BIM to automatically generate a bill of quantities (BoQ) and a cost estimate.

The benefits of this program are the automation of quantity take-off and cost estimation, reductions in lead times and errors in the estimation process.

The limitation to the current tool however is that it currently covers the following trades: reinforced concrete, post tensioning, formwork, masonry and structural steelwork at detailed documentation stage.

The automated estimator could be useful for several users, including:

- Architects/designers
- Built asset contractors
- Cost consultants
- Quantity surveyors

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