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BIM for Sustainable Whole-of-life Transport Infrastructure Asset Management

Adriana X. Sanchez[1*], Judy A. Kraatz[2], Keith D. Hampson[1], and Sudharsanan Loganathan[3]

[1]Sustainable Built Environment National Research Centre (SBEnrc), Curtin University, Perth
[2]Griffith University, Brisbane
[3]Queensland Department of Transport and Main Roads, Brisbane

[*]Corresponding author. Email: a.sanchez@sbenrc.com.au

ABSTRACT: *The US National Institute of Standards and Technology (NIST) showed that, in 2004, owners and operations managers bore two thirds of the total industry cost burden from inadequate interoperability in construction projects from inception to operation, amounting to USD10.6 billion. Building Information Modelling (BIM) and similar tools were identified by Engineers Australia in 2005 as potential instruments to significantly reduce this sum, which in Australia could amount to total industry-wide cost burden of AUD12 billion.*

Public sector road authorities in Australia have a key responsibility in driving initiatives to reduce greenhouse gas emissions from the construction and operations of transport infrastructure. However, as previous research has shown the Environmental Impact Assessment process, typically used for project approvals and permitting based on project designs available at the consent stage, lacks Key Performance Indicators (KPIs) that include long-term impact factors and transfer of information throughout the project life cycle.

In the building construction industry, BIM is widely used to model sustainability KPIs such as energy consumption, and integrated with facility management systems. This paper proposes that a similar use of BIM in early design phases of transport infrastructure could provide: (i) productivity gains through improved interoperability and documentation; (ii) the opportunity to carry out detailed cost-benefit analyses leading to significant operational cost savings; (iii) coordinated planning of street and highway lighting with other energy and environmental considerations; (iv) measurable KPIs that include long-term impact factors which are transferable throughout the project life cycle; and (v) the opportunity for integrating design documentation with sustainability whole-of-life targets.

KEYWORDS: building information modelling, transport infrastructure, operational cost, energy targets.

1 Introduction

The 2014 Intergovermental Panel on Climate Change (IPCC) highlights that Australia is particularly vulnerable to the effects of climate change due to intensifying weather events which are already leading to more frequent and intense flood and heat damage to infrastructure. Additionally, the uncertainty around changing rainfall patterns will remain a significant challenge for adaptation and planning [29]. Australian transport agencies will therefore face a range of new challenges that will need to be addressed throughout the design, construction, operation and maintenance of new infrastructure. A 2013 study [42] found that road agencies identified more frequent and costly maintenance as the most relevant trend, followed by the need for more resilient infrastructure, and funding constrains for new projects and maintenance of existing infrastructure. Roads contribute significantly to climate change through their construction, maintenance and use. It is therefore important to consider sustainable alternatives to managing transport infrastructure throughout its life cycle including maintenance cost. Australia currently spends some AUD5 billion due to maintenance of roads and this amount is expected to increase by 30% by 2100 [41].

To face these challenges and make whole-of-life transport infrastructure management more cost efficient, transport agencies will have to consider the adoption of a number of new technologies and processes. This will help them in responding *to the pressures associated with the future of roads and remain at the cutting edge of best practice on road planning, assessment, building and management* [42].

Building Information Modelling (BIM), also known as Virtual Design and Construction (VDC), is both a technology and process that could assist transport agencies to be more cost effective through better planning and higher productivity. BIM can also provide sustainability benefits by means of better analysis of the impact of alternative designs and key performance indicators that can be monitored and optimised for throughout the life cycle of the asset. This paper explores sustainability benefits that could be realised through wider implementation of BIM in whole-of-life asset management of transport infrastructure.

2 Building Information Modelling

BIM can be described as *a set of interacting policies, processes and technologies generating a "methodology to manage the essential building design and project data in digital format throughout the building's life-cycle"* [34]. In this sense, BIM can be seen as more than *a digital representation of physical and functional characteristics of a facility* [3] or a *collection of defined model uses, workflows, and modelling methods used to achieve specific, repeatable, and reliable information results from the model* [23].

Mature BIM is a *socio-technical system* that can be used to improve team communication throughout the project life cycle, produce better outcomes, reduce rework, lower risk, provide better predictability of outcomes and improve operation and maintenance of an asset. These are some of the benefits identified by the US infrastructure sector [21].

A common concern among new adopters, especially small and medium enterprises (SMEs), is the initial cost of implementing BIM and its applicability to small infrastructure projects. A survey carried out in the US [21] found that, due to their shorter duration, small projects present more opportunities to introduce the use of BIM and the smaller size of organisations is advantageous in driving higher levels of implementation. This survey showed that 67% of all BIM users report a positive return on investment (ROI) for BIM use in infrastructure projects and 38% of those firms measuring ROI considered sustainability as an important contribution to higher ROI [21]. In Australia, over half of the firms that focus on infrastructure projects reported over 25% ROI from implementing BIM [20].

This ROI has the potential to rise significantly as implementation of BIM becomes more common and widespread in the industry [19, 22].

Furthermore, a 2014 report by the Australian Productivity Commission examining the infrastructure sector advocates that clients should invest more in the initial design and conduct better cost-benefit analysis while improving the quality of information used to assess tenders. This report also recommends the use of BIM for complex projects from the early design phases *to provide for lower construction costs and the selection of the lowest 'whole-of-life' design option*. The Commission also recommends clients *give serious consideration to where in their better practice guides they may specify the use of BIM* [1].

In terms of overall cost savings, BIM was identified by Engineers Australia in 2005 as one instrument that has the potential to significantly reduce the total industry cost burden from inadequate interoperability in construction projects from inception to operation. In Australia, this cost could amount to total of AUD12 billion annually [28] and in US [13] study was shown to be mostly borne by clients and operation managers.

3 BIM and Sustainability

Infrastructure Australia highlighted the importance of including potential impacts of climate change and other environmental impacts when making decisions on urban transport infrastructure planning, investment and management [14]. In addition, Australian transport agencies have set a series of sustainability strategic targets that should be considered when planning new assets. In order to have more effective action plans, these should be linked to Key Performance Indicators (KPI) that can be transferred and monitored throughout the asset's life cycle [31].

It has been argued that traditional CAD planning environments lack the capability to perform analysis related to sustainability targets, which have higher impact when carried out at the early design and pre-construction stages. This leads to the *inefficient process of retroactively modifying the design to achieve a set of performance criteria* [2].

Furthermore, research has shown that programming and asset specifications developed in the early design phases determine up to 80% of the environmental pollution and operational cost of assets [5].

BIM provides the opportunity for information from different disciplines to be integrated within the model and also provides the tools to measure and analyse sustainability performance of the project and resulting asset throughout its life cycle. Effectively, BIM can reduce the cost of performing such analysis and monitoring *by making the information required for sustainable design, analysis and certification routinely available simply as a byproduct of the standard design process* [2].

The use of this type of integrated management systems has also been observed to produce additional benefits such as: *minimisation of documentation and records, integrated and univocal strategies and policies and non-conflicting objectives, cost saving by optimising time, resources and responsibilities, simplification of internal and external audits, interaction and co-operation with stakeholders, improved image and management reliability,* [and] *more sustainable management* [6].

Finally, a lack of knowledge transfer related to sustainable alternatives and their performance specifications is commonly observed between transport infrastructure projects. As highlighted by Newman et al. [25], this hinders the use of those alternatives that have been implemented successfully in previous projects and forms a major barrier to the use of innovative materials that might reduce the environmental impact and cost of new infrastructure construction projects. BIM can help to reduce this gap by increasing the transferability and accessibility of such information to the organisation as a whole.

The following two sections provide specific examples on how BIM can facilitate the achievement of sustainability targets in whole-of-life transport infrastructure construction and management.

4 Alternative and Scenario Analysis: Better Informed Decision Making

Alternative and scenario analysis is a tool that can be used to support informed decision making by taking into account emerging challenges; developing, testing and adopting new approaches in a virtual environment; and therefore allowing a better understanding of how different issues relate to each other and what the repercussions of each decision are [26].

Based on current global trends from the construction and other industries, it seems apparent that information and communication technology (ICT) tools will become more integrated into decision support and management systems [17]. BIM in particular can eventually lead to a fully integrated virtual design and construction approach, where the projects are completely simulated before breaking ground. An example of this approach from the health care facility construction sector is the Salford Medical Centre in the UK which was completely designed in BIM (including quantities, location and schedule of material movement and disciplines' workflow). This led to the project being delivered 6 weeks ahead of schedule (with a 28% increase in productivity), reduced rework (between 60% and 90%), and achieving all the sustainability targets set by the client [12].

BIM can therefore provide beneficial project outcomes by enabling the rapid analysis of different scenarios related to the construction process and the constructed facility through its life cycle [8].

In building construction, the rising cost of electricity and increasing environmental concerns has led to a demand for designs that minimise the environmental impact of both construction and operations phases [2]. BIM is starting to play a significant role in this space through better planning and more accurate alternative analysis for better energy performance, reduced water and materials use, among other [20].

Because of the key role transport infrastructure has in society and the scale (Australia had some 900,000 km of road alone in 2012, enough to tour the earth 22 times) [4], it is important to consider its future environmental, social and economic impact [26] and the hazards that might affect it in a changing climate. As in the building industry, BIM has the potential to facilitate such analysis and inform decision making for a more sustainable and resilient transport infrastructure.

4.1 Energy

Environmentally conscious *innovative road builders now see resource efficiency and carbon neutrality as paramount to the success of their projects* [25]. In Australia, transport authorities have a central role in driving initiatives to reduce the environmental impact of the construction process and operation of the final asset. Energy use and the associated Greenhouse Gas Emissions are a significant part of these impacts and often used as KPIs for environmental goals [32].

The critical age of most road infrastructure is 50 years [24]. Over this period, lighting a typical arterial road and freeway ramp would consume 640 kWh/m of road lit by street lighting [25]. Over the same period, *an intersection on an undivided road is estimated to consume 1,346,000 kWh (310-1,840 t CO_2-e) if incandescent lighting is used* [25]. This energy consumption can be significantly reduced by better planning the lighting post location and the type of bulbs used. For example, the New York City Department of Transportation (NYCDOT) determined that the city roads used annually 4.32 billion kWh (approximately 6% of total municipal energy use). After considering different alternatives NYCDOT started trials to replace over 80,000 bulbs to low-energy alternatives and virtually all their traffic signals to LED. This produced an 81% annual energy saving and an approximate financial saving of USD6.3 million a year due to lower energy and maintenance cost [25].

This type of analysis could be carried out in BIM as a routine part of the design phase of any new project; using product specifications and information from previous projects for the alternatives analysis and through experimentation with location and type of lighting. This could provide an additional benefit to facility managers if an accurate digital model of the road network is developed which includes maintenance schedules and specifications. These models could eventually be integrated into smart lighting systems such as those planned to be used in the Netherlands [7] and those already in use in Scandinavia [9]. It could also help lower maintenance cost which in Australia amounts to more than AUD7 billion annually for maintaining and renewing the road estate, of which AUD5.5 billion is paid by the States [15].

Similar potential savings could be realised if this approach is extended to tunnels and the rail network.

4.2 Disaster Preparedness and Recovery

BIM has the potential to be used in two key ways to help Australia face the challenges outlined by the IPCC [29] and become more resilient. With intensifying weather events, it is expected that Australia will have more disaster events. The societal, economic and environmental impact of such events will depend on actions taken by the government to prepare, mitigate and recover.

In terms of preparedness, BIM can be used to test the impact of different scenarios on different infrastructure designs [33]. Adding another layer of information to the decision making process could help understand how the infrastructure asset will hold during the event, and how it will affect the level of disaster and the disaster risk map. For example, how a new elevated road can modify the flood hazard map of a specific area or using the model for initiatives such as the Bushfire Cooperative Research Centre Fire Behaviour Modelling [10].

The models can also be integrated into disaster preparedness planning by *tapping into and distributing building information in real time to remote monitoring stations and emergency responders* [40]. The availability of such information, for densely populated urban areas as well as for remote rural areas, can *improve the efficiency and effectiveness of incident responses, and minimize safety risks to emergency responders* [40].

BIM is a powerful tool for analysis, and can play a central role in disaster preparedness when leveraged during the very early schematic design phase of a project [33]. For example, when designing tunnels, fire safety and ventilation can be considered in more detail by integrating the 3D model into simulations of different scenarios, which can then be used to develop and coordinate emergency response efforts.

By designing infrastructure which is more resilient and integrating information from the model into the disaster response planning process, Australia can help reduce the impact of more frequent and intense weather events.

5 BIM in Transport Infrastructure: Hallandsås Tunnel, Sweden

In 2009, the Swedish Government appointed a committee to study the productivity and level of innovation of public clients, and provide recommendations to improve current practices [18].

Trafikverket is the Swedish Transport Administration responsible for the design, construction, operation and maintenance of all state owned roads and railways. This agency also develops long-term plans for the transport systems on road, railway, sea and air [35].

The main recommendations of the committee included that public-sector clients should consider long-term actions that: provide improved planning and procurement to allow businesses to perform tasks in a more efficient and creative way, and increase the proportion of *turnkey* projects [18]. Trafikverket addressed the challenge of increasing their productivity by developing a strategy that would lead to a systematic implementation of BIM. This plan includes: (i) the development of a number of large and small scale roads, tunnels and rail pilot projects; and that all new projects include the use of BIM from 2015 [36].

One of the best known pilot projects is the EUR1.2 billion (AUD1.8 billion) Hallandsås Project consisting of two 8.7 km parallel railway tunnels due to be completed in mid-2015. Some of the challenges of this project include: excavation works through hard rock and soft rock and clay, high water pressure, and significant restrictions regarding leakage to ground water due to sensitive land area. These challenges led to the manufacturing of 40,000 segments to provide a water tight tunnel lining. BIM has been used to: optimise production throughout the different construction stages; coordinate activities between disciplines; increase quality throughout the life cycle (better design and methodology as well as better facility documentation for operations); control cost; and to reduce risk [30, 39].

The project team has used BIM for machine control/guidance, survey layouts, project drawings, clash detection, accurate quantities, specifications and logistics. They expect to use it further for augmented reality visualisation in the coming stages [30].

Based on the modelled design, Trafikverket expects to increase the number of trains per hour from 4 to 24 and the speed from 80 km/h to 200 km/h. Each train is expected to take as much as 30 trucks off the roads and therefore reduce the air pollution produced in the transport of goods [37].

At this point there is no specific information about how Trafikverket has been using BIM to monitor and manage the environmental impact of the construction and operations of the tunnel. However, the model is being used as the single source of information for the project. Therefore, environmental impact analysis and the consequent considerations would be included in the model. Additionally, a key objective of the project is to integrate the information management throughout the life cycle of the asset. It is therefore expected that it will be integrated with the processes that aim to achieve their long-term environmental goals.

Additionally, one of Trafikverket's highest priorities is to include efforts to reduce the energy consumption of Swedish transport infrastructure into ongoing business development activities [38]. This is expected to be combined with their BIM implementation efforts.

For example, in 2013 the Swedish National Road and Transport Research Institute (VTI) identified factors that constitute barriers or incentives for more energy efficient road and street lighting. They found that the worst performing municipalities had not coordinated the planning of road and street lighting with any other strategic issues [16]. BIM could assist Trafikverket and Swedish municipalities to overcome this barrier.

Trafikverket also identified a number of methods that must be considered in any future project to reduce operational energy cost [27] with significant savings proven through pilot projects (up to 75-80%) [11]. This kind of information could be integrated into the design phase through scenario and alternative analysis in BIM.

6 Conclusions

In the coming decades Australia will be facing difficult challenges as a results of a changing climate, made worse by uncertainty around future weather patterns. Australian authorities are responsible for taking steps towards mitigating the environmental and climatic impact of their actions. They are also responsible for increasing the resilience of the infrastructure that supports society. This requires strategic medium to long-term planning which aims to mitigate the consequences of climate change.

Throughout the life cycle of a project, BIM can provide benefits that are not yet being taken full advantage of. This is especially the case for infrastructure assets.

This paper has introduced BIM in the context of sustainable whole-of-life infrastructure management. It proposes that the use of BIM in the early design of transport infrastructure could provide: (i) productivity gains through improved interoperability and documentation; (ii) the opportunity to carry out detailed cost-benefit analyses leading to operational cost savings; (iii) coordinated planning of street and highway lighting with other energy and environmental considerations; (iv) measurable KPIs that include long-term impact factors which are transferable throughout the project life cycle; and (v) the opportunity for integrating design documentation with sustainability whole-of-life targets.

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