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Is it just too good to be true? Unearthing the benefits of disruptive technology

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ABSTRACT

The rate of digital disruption is escalating and placing increasing pressure on organisations to adopt emerging technologies in order to improve their productivity and bottom-lines. Unfortunately, however, many organisations are often being seduced by the purported benefits of disruptive technologies often based on embellished or even falsified claims. This is particularly true in construction, where organisations are being required to embrace disruptive technologies (e.g. Building Information Modelling and Industry 4.0) to address performance and productivity issues. Unsubstantiated claims about expected benefits subvert the justification and benefits realisation process as the change management that is required is downplayed or ignored. It is, therefore, imperative that the business case as part of the process of evaluation, is based on evidence to enable the development of a change management and implementation strategy. In this paper, we present an overview of a longitudinal line of inquiry that sought to examine the benefits of disruptive technology, namely Systems Information Modelling (SIM). Our research revealed that more than a 90 % cost reduction to document electrical systems and a corresponding improvement in productivity was achieved. We suggest that engaging in the process of critical thinking, possessing a conscious awareness and healthy scepticism of technology places organisations in a position of control. As a consequence, organisations are better-positioned to understand the nature of technology and 'how' value can be generated from potential new ways of working.

1. Introduction

> "The point of modern propaganda isn't only to misinform or push an agenda. It is to exhaust your critical thinking, to annihilate truth." (Gary Kasparov)

Being able to engage in reflective scepticism and form a judgment provide the basis of critical thinking (Bailin, Case, Coombs, & Daniels, 1999). The critical thinking process comprises "component skills of analysing arguments, making inferences using inductive or deductive reasoning, judging or evaluating, and making decisions or solving problems" (Lai, Bay-Borelli, Kirkpatrick, Lin, & Wang, 2011: p.2). Considering the copious amounts of information being made available on the Internet often driven by social media based on popularity rather than accuracy, we now can see 'fake news'[1] in its various guises has become the norm within the popular press.

Within the academic community, 'fake news' (e.g., falsification and fabrication of data) can also be found to occur in the scientific literature and can have damaging consequences. The increasing number of retractions of academic papers from journals indicates that 'fake news' is on the increase. Academics will attest to have the requisite abilities to employ critical thinking in their work, but many still fall for and propagate 'fake news' even more. In this instance, we see scholars demonstrating a "diligent spirit of due negligence" (Tourish, 2019: p.2). Repeating false claims results in "Bottomless Pinocchios" being promoted (Kessler & Fox, 2019).

A case in point is the justification for the use of disruptive technologies, such as Building Information Modelling[2] (BIM) in the construction sector which is often based upon spurious cost and productivity claims made by academics, bloggers and software vendors and

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[1] In the form of clickbait, propaganda, parody, sloppy journalism, misleading headlines, and biased reporting.

[2] The US National Building Information Model Standard Project Committee define: BIM as "a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition" (Available at; http://www.nationalbimstandard.org/faq.php)

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the like (Love & Matthews, 2019). Notably, organisations need to be aware that technology is not always the solution to addressing issues associated with productivity. In a similar vein, Green (2013) cogently stated "it seemingly doesn't really matter what the problem is – the answer is always BIM" (p.2).

A good example is the promotion of the benefits of Autodesk® BIM 360™ by Bliss (2017) who suggest that this technology can reduce construction rework. Bliss (2017) informs us that 24 % of rework claims are due to insufficient detail and inaccurate specifications and logistics. This claim alone is of concern as it cannot be substantiated. Indeed, rework is a *wicked* problem that may never be able to be solved due to the constant change and challenges that confront construction (Love & Matthews, 2019). Bliss (2017) suggests that to improve the flow of information to operatives on-site and reduce the time to respond to Requests for Information as result of issues identified in the documentation, a cloud-based repository enabled by BIM 360™ is needed. Bliss (2017) then states that Skanska, a global construction group, adopted this technology and experienced a staggering 948 % return on investment. Again, no evidence is presented to support the claim that use of this software can provide such financial returns. We do not discount that benefits can materialise from utilising Autodesk® BIM 360™, in fact quite the contrary (Matthews et al., 2015). Still, we question these figures used to justify its adoption.

There are numerous examples in Australia of studies that have been overly zealous in their claims of the quantifiable cost and productivity benefits that can materialise from implementing disruptive technologies in construction such as Brown (2008), Foreshew (2014), and Hou, Wang, and Truijens (2015) to name a few. Moreover we often see applications for research funding setting 'unrealistic targets' for disruptive technologies in a hope to persuade funders and their reviewers of the benefit and significance of a proposal (e.g., Build 4.0 CRC[3]).

There are also examples in the construction and engineering literature where figures extolling the benefits of disruptive technology are often taken out of context, mis-quoted or even falsified. A notable example where a fake figure is used to promote the benefit of BIM can be found in a report published by Allen's Consulting (2010). In their report, it states that: "BIM technology can reduce the time to complete a project by 7 per cent, as all stakeholders have access to critical information, including schedule and budget information, materials quality and costing information, performance, utilisation, and financial information (Brown, 2008, p. 10; CRC for Construction Innovation, 2007)" (p.15). However, a review of the references cited by Allen's Consulting reveals that there is no mention and evidence to support the claim of 7 % reduction in time by the CRC (2007). Brown (2008: p.10) refers to CRC (2007) and states that they have "calculated that the use of BIM can reduce project time by at least 7 %". Again, no such evidence is presented by the CRC (2007) to support their assertion.

In light of the above 'fake news', it is not surprising that some Australian construction organisations may be hesitant to embrace BIM, particularly after the experiences of several landmark projects. For example, the Adelaide and Perth Children's Hospital were widely touted as being 'best practice' cases for BIM adoption (Mills, 2016; Sanchez, Hampson, & Mohamed, 2015), but both projects significantly ran over their budgets and schedules (e.g. Keane, 2018; Young, 2018). Perhaps, however, if BIM had not been used, then far higher costs and schedule overruns may have been experienced. We will, however, never know.

To suggest that a technology such as BIM can reduce project time without sound evidence and a context demonstrates a blatant disregard for the complexities associated with the workflows and processes of construction. Unsubstantiated claims about expected benefits subvert the justification and benefits realisation process as the change management that is required is downplayed or ignored. Without a doubt, disruptive technologies can potentially transform the construction sector. Still, we need to be pragmatic about the expected benefits that can be realised and not succumb to making false claims and promises. It is, therefore, imperative that the business cases for disruptive technologies as part of the process of evaluation is based on evidence and robust change management and implementation strategy (Love & Matthews, 2019).

Exaggerating and making false claims about the benefits that can be acquired from disruptive technologies is simply 'bad science'. When 'good science' is practiced and presented within a given context to support the use of disruptive technology, then a compelling case can be put forward for organisations to examine 'how' it can provide them with a competitive advantage. Acknowledging the need for 'good science' to support the process of technology evaluation, we show how a disruptive technology,[4] namely Systems Information Modelling[5] (SIM), can provide significant cost and productivity benefits during engineering design and construction of an asset. We provide a synopsis of a longitudinal line of inquiry where we repeatedly examined the benefits of SIM. Our research has been able to demonstrate, with evidence rather than conjecture, not only cost and productivity benefits, but also those of an ancillary nature that can transpire from adoption. We commence our paper by providing a context for introducing a SIM. Then, we summarize the empirical work we have undertaken to demonstrate the benefits of using this disruptive technology, with reference to practice.

2. Understanding the problem: it's all about information management

Information management aims to ensure that *the right information is available to the right person, in the right format at the right time*. While in theory, this aim may appear to be straightforward, in practice it is a complicated process, especially within the context of construction projects, which involve multiple organisations that all have different information requirements to achieve their goals. It is the inability to effectively and efficiently manage information in construction projects that often results in low levels of productivity and poor performance (i.e. ability to meet expected deliverables).

The need for standardisation (e.g., product and processes) and a structured approach for managing information in projects has been widely espoused in construction (e.g., Tolman, 1999; Laakso & Kiviniemi, 2012). Interoperability of data is also a problematic issue in construction, though with the introduction of BIM some headway is being made to standardise the way we manage information with classifications such as Uniclass 2015 leading the charge. More broadly, however, BIM provides the underlying platform for digitally integrating processes throughout a project's life-cycle. So, without having a structured and standardised data format in place, which is enabled by BIM, the full benefits of three-dimensional (3D) printing, robotics, visualisation, intelligent content extraction, predictive analytics, cognitive computing and the like., are unattainable. This situation also applies to nascent disruptive technologies such as artificial intelligence (AI), blockchain, cyber-tracking, and spatial analytics.

A considerable amount of attention has been focused on creating 3D intelligent building information models that can be used to create digital twins for managing operations and maintenance of assets. However, issues surrounding how information is generated, exchanged,

[3] Details can be found at: https://www.building4pointzero.org/

[4] Disruptive technology refers to any enhanced or completely new technology that replaces and disrupts an existing one, rendering it obsolete. In this case of a SIM, we are suggesting based on the empirical evidence we have accumulated that it should replace CAD-based systems that have been traditionally used to engineer and document electrical systems

[5] A SIM is supported by software such as Digital Asset Delivery (https://www.dad.net.au)

and used in a structured and standardised format in building information model's remains unresolved. More surprisingly, information for electrical, instrumentation, control, communication and power systems (from now on referred to as electrical systems) that enable an asset to operate, is often superficially considered in a building information model (Love, Zhou, Matthews, & Luo, 2016).

Electrical systems are a central component of our critical infrastructure, and with the exponential growth of information system networks that interconnect administrative, business and operational systems, they are increasingly becoming vulnerable (Moteff & Parfomak, 2004). Should an asset's electrical system be compromised by a third party (i.e., by a threat or attack), or is damaged, or fails, then it is imperative to know which aspect has been compromised and what requires immediate attention. In this instance, we need to have information about the pieces of equipment and cables that are impacted, such as their location, type, connectors and specification (e.g., manufacturers details).

Electrical systems are just one of many elements that need to be considered in the BIM process and perhaps are the most complex of all. Up until now, however, there has been limited research that has modelled the information requirements of electrical systems in construction[6] projects (e.g., Zhou, Love, Matthews, Carey, & Sing, 2015; Love, Zhou, & Matthews, 2017; Love & Matthews, 2019). Nevertheless, we often see those who promulgate the benefits of BIM providing *carte blanche* claims of its cost and productivity performance outcomes without understanding and knowing 'how' critical elements within a building information model can influence an asset's performance. Construction organisations ought to re-frame from listening to the rhetorical spin that have been and continue to be placed on 'why' disruptive technologies will be of benefit and instead start focusing the on 'how' they can be realised (Matthews, Love, Mewburn, & Stobaus, 2018; Love & Matthews, 2019). We now introduce SIM and show how we have been able to reify its benefits, which are being realised by a wide range of businesses in the energy, resource, and transport sectors.

3. Systems information modelling

A "SIM is a derivative of BIM, but 'Building' is replaced with 'System' to represent the process of modelling complex connected systems, such as electrical control, power and communications, which do not possess geometry" (Love et al., 2016a: p.156). A SIM takes a discipline-specific perspective and is interoperable with a building information model. When a SIM is applied to engineer and document a system, all physical equipment and the associated connections are modelled in a relational database with each component modelled only once resulting in a 1:1 relationship between the SIM and the real world (Zhou et al., 2015). While BIM is being used to model geometric properties, Computer-Aided-Design (CAD) remains the preferred method for engineering and documenting electrical systems in the infrastructure sector (e.g., energy, resource, transport, and mineral processing) (e.g., Love, Zhou, Matthews, Lavender, & Morse, 2018). When CAD is used, each object in the real world may appear on multiple drawings, and each drawing will contain several objects. A n: n relationship is formed between the real-world objects and the drawings (Love, Zhou, Sing, & Kim, 2013; Love, Zhou, & Kim, 2014). In a SIM an object includes all known data for its corresponding asset item. In Fig. 1, an overview of a SIM and how information is structured (e.g., type, location and group view) and managed is presented.

4. Summary of empirical SIM studies: a process of replication

The replication of studies forms an integral part of 'good science' and is required for the advancement of knowledge. In the research we present to support the adoption of a SIM, a case study approach was adopted. The process of replication in our study focused on applying the same method, using different projects, to determine the cost and productivity benefits, with the provision of context (i.e. examples of documentation errors and the like).

Fig. 2 provides an overview of the research process that we followed throughout our line of inquiry. Replication is essential for several reasons, as it aims to (Heffner, 2016): (1) provide assurance that results previously obtained are valid and reliable; (2) determine their generalisability or the role of extraneous variables that we examined; (3) apply the results to real-world situations (e.g., to practice work); and (4) identify new research directions in consideration of previous findings from similar studies. A case study approach was used in our research as we aimed to determine 'why' and 'how' a SIM could provide cost and productivity benefits.

4.1. Preamble: research context

The concept of a SIM was first proposed in 1994 by an Australian instrument, electrical and control system engineering company – I&E Systems Pty Ltd. They found that the cost of design-related activities was up to 70 % of their total project expenditure. Analyses revealed that the limited nature of paper-based methods/workflows significantly contributed to the high cost of design which required duplication of information on multiple documents often resulting in errors and omissions and therefore increasing the cost of labour. I&E Systems realised there was a need to shift away from the traditional paper-based methods to a more efficient systematic digital modelling approach to address this problem.

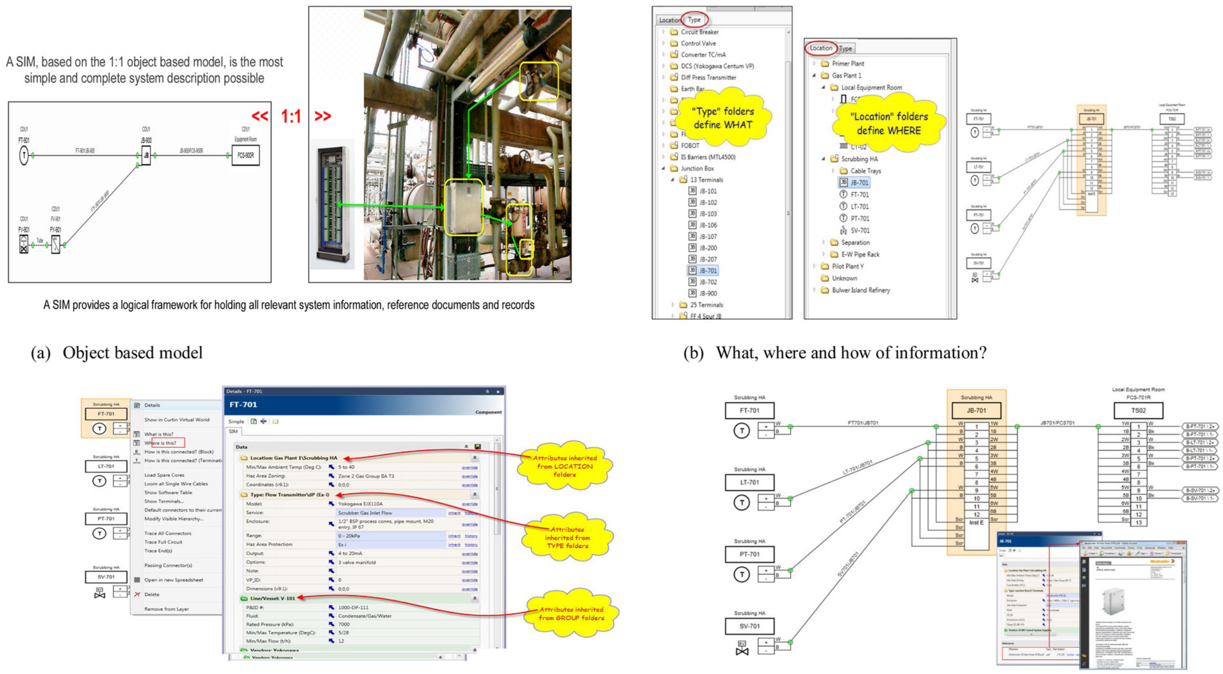
I&E Systems initially informed us that the use of a SIM could significantly reduce the cost and time to engineer and document electrical systems by a staggering 90 %. Our perfunctory thoughts resulted in us initially thinking that such benefits were 'just too good to be true'. With the agreement of I&E Systems, we undertook an independent study to determine the benefits of a SIM, particularly those associated with its cost and productivity. I&E Systems provided us with access case study projects that they had been completed. We were provided with a list of projects and selected ones from different industrial sectors (e.g., mining, transport, and energy). We now summarise a sample of the case studies we undertook to determine the benefits of SIM.

4.2. Cost and productivity benefits

4.2.1. Stacker conveyor

Our initial case study, in accord with the process presented in Fig. 2, focused on examining the 'as-built' drawings of a Stacker Conveyor in a $2.8 billion Iron Ore project (Love et al., 2013, 2014). We analysed 106 CAD drawings and a cable schedule. With the assistance of an independent electrical engineer, we found drawing omissions were the most prevalent form of errors, followed by omissions from the cable, labelling mistakes and inconsistent labelling. We calculated the estimated cost for an electrical engineer to rectify the drawings. The engineer provided us with 'average' times to attend to an error and an hourly rate. We also observed that equipment and cable schedules appeared simultaneously on different CAD drawings. Repeating information is costly and time-consuming exercise – it is also unnecessary. For example, we found the same 446 components and cables appeared in three separate documents. We re-modelled the 'as-builts' using a SIM found that the average time to produce a single drawing was two hours compared to the estimated 39 h using CAD. Using a SIM to create the 106 electrical drawings and cable schedule could have saved 4056 person-hours and $523,000. Therefore, a 94 % cost saving and improvement in productivity could have been attained in this particular case.

[6] In this paper we use the term construction to include building, commercial and institutional, industrial, transport, and heavy engineering projects.



(a) Object based model

(b) What, where and how of information?

(c) Data inheritance

(d) System information model

Fig. 1. Management of information in a SIM.

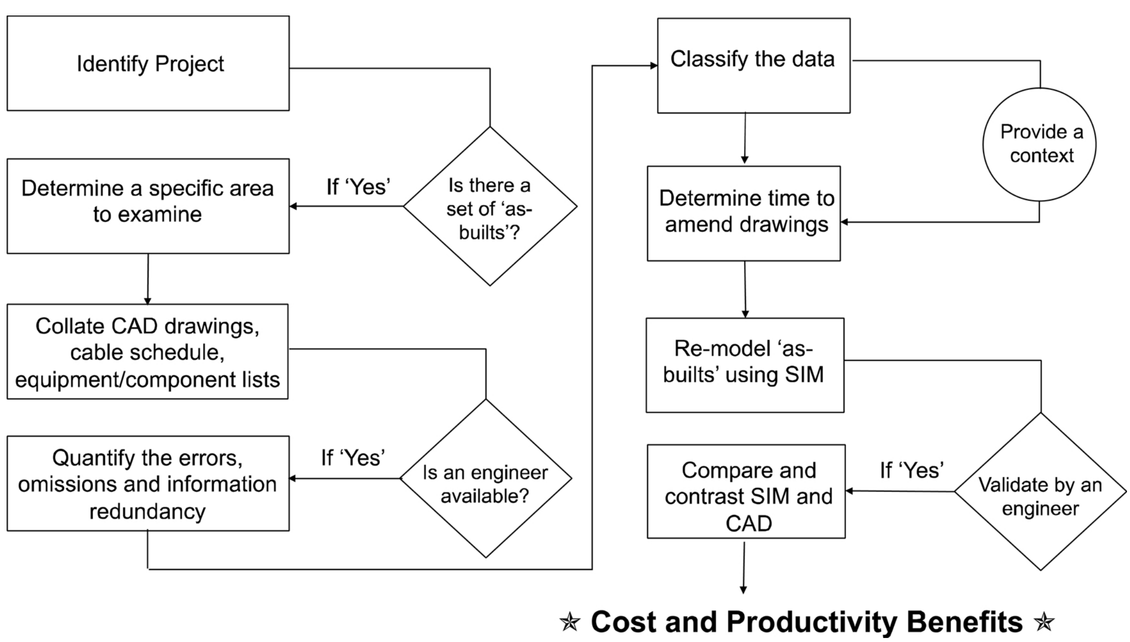


Fig. 2. The process to determine the cost and productivity benefits of SIM.

4.2.2. High voltage switchgear system

Our follow-up study examined the cost and productivity benefits examined the 'as-built' CAD generated documentation for a High Voltage Switchgear System (HVSS), which formed part of a Supervisory Control and Data Acquisition upgrade within a geo-thermal power plan (Love, Zhou, Matthews, & Edwards, 2016). Again, following the procedure identified in Fig. 2. The total number of 'as-builts' for the HVSS was 267. We identified 89 errors and 49 omissions on the CAD drawings

Information redundancy was rife on this set of 'as-builts'. For example, five drawings each contained over 100 components while another had 200. In light of errors, omissions and information redundancy, we retrospectively created a SIM from the CAD 'as-builts'. A total of 80 person-hours was required for an engineer to create the SIM model in comparison to the 10,680 person-hours needed to produce the CAD drawings. Also, the cost to document in CAD was $1,388,400 compared to $12,000 using a SIM. The cost reduction and productivity improvements were both approximately 99 %.

4.2.3. Domestic gas upgrade for an LNG plant

In the case, we examined how a SIM could be used within the design of a Liquified Natural Gas (LNG) plant by making specific reference to upgrading its domestic gas condensate metering system. We examined the 716 'as-built' CAD drawings, which were estimated to cost AU $4,124,160 to produce. Using a SIM, the cost would have been

$214,600. In this instance, there would be no requirement for a draft person, as an engineer can directly generate the SIM equivalent drawing. Moreover, there is no longer a need for the engineer to spend time checking and approving drawings. We observed that a 95 % cost reduction would have occurred to document the design using a SIM for this metering up-grade project.

4.2.4. *Copper mine: identifying cost savings for future plants*

A new copper smelter for a processing plant was designed and constructed at a value of US$800 million to minimise production costs. The 'as-built' documentation for the copper smelter comprised of 653 drawings and possessed a significant amount of errors and omissions (Love, Zhou, Matthews, & Sing, 2016. For example, there were 212 errors identifying cables as being unarmoured when they should have been armoured. In the case of omissions, there were 21 instances where the motor heater power supply was missing and 81 instances of cabling being incorrectly sized. By constructing a retrospective SIM, we able to eliminate the information redundancy that prevailed in the CAD drawings identify the errors, and omissions and determine cost savings that could be incorporated into future plants. In the smelter's plant design, some of the transformers had been mounted at the field motors. By relocating the existing transformers from the motor to the starter, not only would savings in cable length be achieved but also the person-hours for its installation. Notably, if the existing transformer had been designed following within a SIM-based environment there errors and omissions would most likely have been identified, and a total of 12 instrument cables would have been saved, which represents a total length of 2185 m. While the transformer had already been installed on this mine and others planned, we demonstrated that future smelters could be constructed with significant savings, as noted in Table 1, by ensuring the transformer is located next to the motor starter.

4.3. *Ancillary issues*

We present a summary of the costs benefits and risks we have observed from using a SIM in Table 2. The benefits of using a SIM are not restricted to engineering and documentation. A SIM can be used throughout a project's life-cycle and with its real benefits being realised during the process of asset management (Love et al., 2018; Zhou et al., 2015). Within a SIM information is structured and managed in a digital format from a project's commencement to its hand-over. As a result, the issues associated with CAD-based systems (e.g., information redundancy) are eliminated. The SIM acts as a single repository for all information (e.g., vendor manuals, test certificates and reports, and maintenance records) required to design, construct, commission and manage a complex connected system. Also, a SIM-only needs to be created once for an entire system's life. This is in stark contrast to CAD drawings, which need to be re-drawn/modified and re-issued to accommodate necessary changes. The object-oriented modelling and data inheritance aspect of a SIM results in information integrity; data is never repeated. An automatic audit trail of all activities, by every user, can be created and so engender accountability in a project. To this end, SIM ensures that *the right information is available to the right person, in the right format at the right time*.

Table 1
Example of future cost savings by placing a transformer next to its motor.
Adapted from Love et al. (2016d: p.419)

Description	No. of Instances	Cable Length (m)	Cost Reduced ($)		
			Material	Person-hour	Total
Relocate Transformer	12	2185	13,110	22,942	36,052
Relocate Local Control Station	10	1925	13,475	20,212	33,687
Redundant Cables	8	815	3954	8557	12,512
	4	640	4480	6720	11,200
	32	1440	9010	15,120	24,130
	10	2315	17,144	24,307	41,451
	24	5480	50,288	57,540	107,828
	4	650	9914	6825	16,739
	4	550	10,959	5775	16,734
	4	550	13,750	5775	19,525
	2	430	3751	4515	8266
	1	40	937.1	420	1357
Total	115	17,020	150,772	178,708	329,481

Table 2
Cost, benefits and risks of SIM.
Source: Love, Zhou, Matthews, and Locatelli (2019).

Construct	Criteria	High	Medium	Low
Cost	Software and upgrades		✓	
	Training		✓	
	Production of documentation/digital model			✓
	Life-cycle management of asset data			✓
	Labour (e.g., no longer a requirement for a drafts-person)			✓
Benefit	Productivity	✓		
	Information redundancy			✓
	Usability and manageability	✓		
	Teamwork features (e.g., collaboration)	✓		
	Consolidated point of truth	✓		
Risk	Digital obsolescence	✓		
	Interoperability	✓		
	Contractual issues (e.g., requirement to use a SIM)		✓	
	Propriety obsolescence	✓		
	Data accessibility (e.g. reliance on the cloud)	✓		
	Change management (e.g., new processes and practices associated with SIM adoption)		✓	

4.3.1. *Benefits in practice*

Besides the cost and productivity benefits we identified above, two particular organisations that realised the value of a SIM were the Public Transport Authority (PTA) (Love et al., 2018)

and Fortescues Metal Group (FMG) (Love, Zhou, & Matthews, 2016; Sheedy, 2016). The PTA recognised, as part of a continuous improvement strategy, that they needed to digitise their asset management processes and procedures. The PTA became aware of the potential benefits of a SIM and therefore engaged us to determine 'how' it could be effectively utilised by them.

We retrospectively created a SIM of the electrical systems for a sample railway station from existing 'as-built' CAD drawings. In doing so, we identified the errors, omissions and information redundancy embedded within them. As in other case studies, the 'as-builts' did not reflect what had been installed. To ensure the SIM was interoperable with existing PTA software platforms, it was linked to the building information model through the Industry Foundation Classes data format. The mapping between the SIM and PTA's asset management software system (Ellipse) enables the engineering and documentation data that is accumulated during the design and construction process to be effectively transferred so it can be used during the operations and maintenance phase of an asset. Having asset information in a digital format in a single repository provided the PTA with the ability to ensure *the right information is available to the right person, in the right format at the right time*, and as a result, they are now enacting SIM in their work practices.

A SIM was used during the construction of FMG's North Star Magnetite Processing Plant Stage 1. The capital expenditure for electrical, instrumentation and control systems (ECIS) was $43.5million. The use of a SIM resulted in a 50 % reduction in both documentation hours and construction verifications, and 80 % less documentation being handed-over at practical completion. Also, the progress of the ECI's installation was able to be monitored in real-time, and field devices were capable of being bi-directionally linked from the SIM to a 3D model so that they could be visualised. At the time of our study, this was the first paperless construction project undertaken in Australia (Love et al., 2016b).

4.3.2. New research directions

While there are many benefits associated with implementing SIM, it is incongruous with established work practices. It, therefore, may be subjected to unhealthy scepticism and a lack of legitimacy, especially as its cost and productivity benefits, particularly for project documentation, may appear too good to be true. However, how a SIM's legitimacy is created and enacted is dependent on critically questioning 'how' it can improve work practices and by demonstrating its relevance, particularly during an asset's operations and management. We, therefore, suggest that future SIM-based research needs to focus on two particular areas: (1) the creation of life-cycle benefits realisation strategy; and (2) generation and utilisation of a dynamic-digital twin[7] that is *entirely* interoperable with Industry 4.0.

5. Epilogue

With I&E Systems, we saw an initial need to reduce the cost and improve productivity of documenting for electrical systems. I&E Systems engaged in the process of critical thinking and questioned the underlying rationale for using CAD. Of note, there have been limited changes to how electrical drawings have been c7reated since the production of Thomas A. Edison's 'System of Electric Lighting', which was printed March 22nd 1881. The upshot of this process of questioning led to the concept of a SIM. While we were initially sceptical about the benefits that were purported by using a SIM in practice, we demonstrated through the numerous and repeated case studies we undertook that this is, fundamentally, 'game-changing' technology for the digital engineering of electrical systems. The experiences of the PTA and FMG, for example, demonstrate the positive impact that SIM has had on their business.

6. Conclusion

The rate of digital disruption is escalating with new breakthroughs in areas such as AI, and blockchain engendering new opportunities for continued innovation (Duan, Edwards, & Dwivedi, 2019; Dwivedi et al., 2019; Frizzo-Barker et al., 2019). As a consequence, construction organisations are coming under increasing pressure to adopt emerging technologies to improve their productivity and bottom-lines. We urge organisations, however, to question and critically reflect upon the purported benefits of disruptive technologies that are consistently being championed, especially 'if they are too good to be true'. Thus, the justification for adopting technology needs to be evidence-based. We suggest that engaging in the process of critical thinking, possessing a conscious awareness and healthy scepticism of technology places organisations in a position of control. It enables an understanding of what they are dealing with to be garnered and 'how' value can be generated from would-be new ways of working.

We undertook a longitudinal line of inquiry to examine the benefits of a SIM by replicating our approach on different projects. We have provided empirical evidence based on 'good science' to justify that an investment in SIM can provide significant benefits over an asset's life-cycle. Our research revealed that more than a 90 % cost reduction to document electrical systems and a corresponding improvement in productivity could be achievable. Our studies were retrospective in nature, but similar results were repeatedly obtained. The introduction of a SIM requires engineers to shift their mindsets from a position of 1: n to 1:1 and move away from using paper-based systems. An immediate casualty of this new way of working is the role of the drafts-person, which is no longer required. The robust information structure and object-oriented environment of a SIM provides a robust platform for supporting the effective implementation of Industry 4.0.

[7] A dynamic digital twin is "fed by live data flows from a physical asset, for example a building, or one of its components, like a lift motor. Insights and programmed instructions from the digital twin can then impact the physical twin using real-time control mechanisms, for example shutting down a faulty lift or adjusting the temperature of a room" (Lamb, 2019: p.4).

Disclaimer

The views expressed in this paper are the authors' personal views and interpretations of the data collected and are not attributable to I&E Systems. The paper is intended to be a general discussion and does not constitute advice. I&E Systems have not verified the information contained herein. No representation or warranty is made as to the accuracy, completeness or reliability of the information. All liability for any loss or damage incurred by any person as a result of using, acting on, relying on or disclosing any of the information contained in this paper or otherwise in connection with this paper is disclaimed.

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Appendix A. Supplementary data

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