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The 'how' of benefits management for digital technology: From engineering to asset management

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ABSTRACT

With advances being made in digital technologies, asset owners are requiring at hand-over a digital twin of their constructed facility that can be used in real-time to support operations and maintenance processes. While there has been considerable focus on 'why' organizations operating in the construction industry need to adopt digital technologies to enable Building Information Modelling, Internet of Things and Industry 4.0 and thus deliver assets more effectively and efficiently, there has been limited attention given to 'how' they can realize their expected benefits and simultaneously generate value. In light of the drive for organizations to engage with digital technology we bring to the fore in this paper the need for them to legitimize a process of benefits management prior to making a financial investment to understand 'how' digital technologies can coalesce to generate business value and improve their competitiveness. As part of a benefits management strategy, a business dependency network (BDN) can enable investment objectives and their resulting benefits to be linked in a structured manner with an organization's capabilities and changes required to ensure they are realized. Relying on empirical findings derived from nine projects that examined the efficiency gains and advantages of using a digital systems information model from an engineering to asset management perspective, we construct a generic BDN to visualize the structure of multiple cause-effect relationships that are used to organise the capabilities, changes and benefits that need to be considered prior to adoption. The insights and experiences that have emerged from this research provide a frame of reference for construction organizations and asset owners to navigate the benefits realization and change management process, which can be used to ensure their investments in digital technology can effectively respond to business drivers and generate value.

1. Introduction

> "The first rule of any technology used in a business is that automation applied to an efficient operation will magnify the efficiency. The second is that automation applied to an inefficient operation will magnify the inefficiency".
>
> (Bill Gates)

Improvements in competitiveness, productivity, and safety in the construction industry have been spurred, in part, by the automation of traditional manual and paper-based processes enabled by the emergence of an array of digital technologies (e.g., building information modelling (BIM), internet of things[1] (IoT), wearable devices and sensors). Often the underlying driver for organizations investing in digital technologies is to provide managers with rapid and high-quality information to improve decision-making, highlight trends in performance and reduce costs. This ignores, however, the fact that managers possess biases and, regardless of how accurate or reliable the data is, they may not have the cognitive ability to effectively use, or even choose to discard, the information. It is, therefore, imperative that organizations place the users, the people who will create meaning from the information, at the centre of their digitization initiatives. In doing so, organizations need to challenge how employees will, or won't, use data to make decisions, and, at the same time, encourage them to rely on formal analysis rather than solely their 'gut feel'.

The need ('why') to adopt digital technologies is generally well

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[1] There is no consensus on the definition of IoT. A succinct definition has been provided by Rouse [1] who states it is "a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction. The Internet of Things is not itself a new technology. It is, however, a new way of applying existing technologies while leveraging the communication capabilities afforded by the Internet.

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understood and documented. However, to realize their benefits organizations need to ask a series of 'how' questions prior to adopting a technology solution to ensure it adds value to their business operations. If such questioning is not undertaken, there is a likelihood that organizations will be unable to realize the purported benefits that digital technologies can provide. Many of the benefits claimed by software vendors are unsubstantiated (for example, will reduce rework in projects), yet organizations make decisions based on these claims [2]. Despite recognition within construction that there is a need to re-engineer processes to acquire the benefits of information technology [3], a review of the normative literature over the last decade, for example, reveals a different picture. Studies espousing the gains that can be acquired from digital technologies tend to overplay the expected benefits and downplay or even ignore the re-engineering (e.g. change) that is needed for them to be fully realized [4,5]. While there are examples where BIM has been successfully implemented in practice [6], equally there are cases where it has not been able to deliver its expected benefits [7]. We, therefore, need to be cognizant that the adoption of digital technology by construction organizations will require them to embrace change and re-engineer processes so that efficiencies can be maximized.

A process of evaluation is therefore needed to make explicit, both quantitatively and qualitatively, at various points in time, the impacts of implementing the desired technology. In comparison to other industrial sectors, such as health care and manufacturing, studies evaluating digital technology in construction have received limited attention [8–13]. Moreover, when benefits are examined increasing emphasis is placed on financial measures such as return on investment (ROI) and the tangible benefits of technology, particularly in the case of BIM [11]. According to Love et al. [12], the use of a ROI measure "does not accurately reflect the 'real' costs and benefits that are associated with implementing BIM" (p.208).

If construction organizations do not perform a benefits management appraisal prior to implementing digital technologies there is a likelihood that their expected efficiencies will not materialize, as consideration to the strategic (i.e. customer), organizational (i.e. new processes and practices) and cognitive (i.e. how people work) changes will be overlooked. The extent of change that will be required is amplified when new technologies and tools need to be integrated into projects where multiple parties are dependent on information to effectively perform their work. To address this problem, we draw upon our empirical based research to develop a Business Dependency Network (BDN) to enable the realization of benefits for System Information Modelling (SIM). The insights and experiences that emerge from our research provide a frame of reference for construction organizations and asset owners to navigate the benefits realization and change management process.

2. Benefits management

There has been a wealth of studies that have examined the concept of technology evaluation and benefits management in the information systems literature [14–16]. Technology evaluation is referred to as a process of determining by quantitative and/or qualitative means the value of investing in technology [17]. If the benefits of digital technologies are to be realized, then organizations need to understand the meaning of 'value'.[2] In its simplest terms, it can be defined in positive (benefits) and negative (dis-benefits) impacts, which can be categorized as being financial or non-financial [19].

Identifying the benefits and dis-benefits of investing in digital technologies is a challenge for construction organizations "due to the indirect and unplanned effects of such actions" ([17]: p.172). Moreover, benefits and dis-benefits are difficult to determine up-front as they tend to evolve over an investment's life-cycle [20]. Investment in digital technologies therefore needs to be planned and managed [21,22]. By engaging in a process of benefits management organizations can bring to the fore the appropriate information needed for making an investment decision and identifying a way to deliver expected benefits [23]. In sum benefits management can be defined as "the process of organizing and managing, so that potential benefits arising from investment in change are actually achieved" ([24]: p.23). Benefits management is "required for the active management of, and continuous alignment between [project] outputs, outcomes, benefits, and organizational strategy" ([25]: p.1658).

2.1. Understanding the 'how'

Within the construction and engineering management literature the importance of technology evaluation, specifically the process of benefits management has been overlooked or misunderstood [14,26] particularly in the context of the drive for the industry to engage with the IoT and Industry 4.0[3] (i.e. where transformative technologies are used to connect the physical with the digital world). As a result, the changes that are often required to an organization's strategy, structure, processes, and policies as well as the impact of people have largely been ignored. Though, it should be noted that as part of the United Kingdom's 'Digital Built Britain Strategy', facilitated by the 'Centre for Digital Built Britain', it has been recognized that to improve productivity there is a need create and support a workforce within the construction industry that has the requisite knowledge, skills and capability to adapt to a digital work environment and respond to change.[4]

In light of the desire and drive for organizations within the construction industry to engage with digital technology to improve their productivity and performance, we aim to bring to the fore the need to legitimize a process of benefits management. Such legitimization will enable organizations to be better positioned to understand 'how' digital technologies can be integrated to generate business value. Having in place a benefits management strategy ensures that the value and strategic relevance of digital technologies to an organization are made explicit. To support this strategy there is a need to put in place "strategic governance" that can ensure "progress toward the delivery of planning benefits" ([28]: p.53).

Construction organizations, however, seldom establish a governance structure to ensure that the benefits of adopted technology are realized. The deployment of digital technologies is a relatively straight forward process, but understanding 'how' they can be used remains a challenge for organizations [29]. Unfortunately, 'how' technology should be used by a construction organization is often sold by misrepresenting or exaggerating the expected benefits. It has been claimed, for example, that Autodesk® BIM 360 [30] reduces the occurrence of rework in construction, yet no empirical evidence is presented, or has been demonstrated in the academic literature, to support such a claim. In fact, many of the statements made about BIM's ability to reduce

[2] It is outside the scope of this paper to examine the concept of 'value' though a detailed and insightful analysis of the subject matter can be found in Tiernan and Peppard [18].

[3] Baur and Wee [27] state that "the next phase in the digitisation of the manufacturing sector, driven by four disruptions: the astonishing rise in data volumes, computational power and connectivity, especially new low-power wide-area networks; the emergence of analytics and business-intelligence capabilities; new forms of human-machine interaction such as touch interfaces and augmented-reality systems; and improvements in transferring digital instructions to the physical world, such as advanced robotics and 3-D printing".

[4] The Centre for Digital Built Britain is situated at the University of Cambridge and is partnership between the Department of Business, Energy & Industrial Strategy to understand how the construction and infrastructure sectors can use a digital approach to better design, build, operate, and integrate the built environment. Details about the 'Pedagogy and Upskilling Network can be found at: and https://www.cdbb.cam.ac.uk/CDBBResearchBridgehead/Networks/2018Network_PUN

unplanned changes, rework and out-of-sequence work, have been based on surveying the perceptions of practitioners [31].

We do not discount the benefits of using BIM to identify and reduce issues (e.g., clash detection), but rework causation is a *wicked* problem that may never be able to be solved due to the constant change and unprecedented challenges that confront construction [2]. In fact, it is the organizational and social complexity of wicked problems, as much as their technical difficulties, that renders them difficult to solve. Thus, to suggest that rework is reduced using BIM disregards the complexity of the issues at hand [2]. Similarly, it has been reported in the Australian popular press that the adoption of smart Radio Frequency Identification (RFID) tags in the Liquified Natural Gas (LNG) sector could improve productivity by 30% [32]; again, no empirical evidence exists to support such a claim. Unfortunately, there is a danger that this emergent canard may permeate the literature and be used, in part, to support the business case for adopting RFID within the LNG sector. Whenever claims about the benefits of technology are based on academic research, it is important to provide a context and make explicit any assumptions and limitations. On face value claims may appear to be reliable, especially when reported as being innovative in well-respected newspapers. We suggest that whenever claims are made that technology can improve productivity and performance, they should be treated with caution unless they have been substantiated and underpinned by research grounded in 'good science' [33]. While digital technology can provide significant benefits to organizations, it can also result in dis-benefits manifesting, which can result in a series of unexpected problems (e.g., inefficiencies) emerging [12]. Bill Gates' words of wisdom, used to introduce our paper, echo this case in point.

2.2. Delivering benefits

Understanding the business context and the problem that digital technologies will address is fundamental for ensuring benefits can materialize [34,35]. Equally, construction organizations implementing new technological solutions need to initiate a change management process. Highlighting the symbiotic relationship that exists between benefits and change, Peppard [36] states, "benefits are unable to be delivered without change, and change without benefits cannot be sustained". Construction organizations need to acknowledge five underlying principles if they are to realize the benefits of implementing digital technologies [37,38]:

1. Just having technology in place will not confer any benefit or create value. The adoption of technology is a cost and benefits will only materialize from its use.
2. Benefits will arise when technology enables the organization and people to do things differently.
3. Benefits result from changes and innovations in the way we work, so only business managers, users, and customers can make these changes.
4. The use of technology can produce negative outcomes and may even affect the organizations competitive positioning.
5. Benefits must be actively managed so that they can be obtained. The benefits of technology will not arise if a construction organization does not carefully plan and manage against known pitfalls (e.g., integration with legacy systems)

Benefits in conjunction with costs and risks need to be determined at the strategic, tactical and operational levels to accommodate both the tangible and intangible requirements of stakeholders [12]. The basic structure of a benefits realization plan that can be used to support a business case is presented in Fig. 1. The benefits management process comprises five stages [18,39]:

1. *Identifying and structuring benefits*: The process begins by understanding the business drivers for introducing the technology into the organization, identifying all likely benefits and expressing them in business terms (e.g., quantifying and establishing financial benefits).
2. *Planning benefits realization*: Decisions regarding 'how' the benefits are going to be achieved and the resulting changes required. Metrics for performance measure and on-going assessment will need to be developed.
3. *Executing the benefits realization plan*: This stage focuses on 'making it happen' and implementing the change management programs that have been designed (e.g., up-skilling and education of the workforce, mobilizing resources, and communication). Having an effective change management plan in place is just as important as planning the deployment of digital technology.
4. *Evaluating and reviewing results*: Benefits are not static and will need to be monitored throughout the lifetime of the system. This requires the process for evaluation of benefits to be dynamic (e.g. summative, formative and ex-post evaluations).
5. *Discovering the potential for further benefits*: The evaluations that are undertaken are an opportunity for learning and identifying potential additional benefits.

In the next section of this paper we briefly describe the process to develop a Benefits Dependency Network (BDN).

2.3. Benefits dependency network

The BDN was developed by Ward and Elvin [40] to enable investment objectives and their resulting benefits to be linked, in a structured manner, with an organization's capabilities and the changes required to ensure they are realized. Once completed, a robust business case for investing in the digital technology, juxtaposed with a viable change management plan to deliver the expected benefits, can be developed. Fig. 2 presents an example of a BDN's architecture.

Within construction, for example, contractors are often required to implement BIM in their projects, and therefore include a price for providing this service in their tender. Rarely, if at all, is a specific business case for its adoption undertaken [6]. As a consequence, the degree of change management required to ensure the benefits of BIM are realized may be overlooked [6].

To develop a business case the following example questions should be answered ([41]: p.47): "What must we improve? What improvements are necessary? What benefits will be expected by each stakeholder if the investment objectives are realized? How will each benefit be measured? Who owns each benefit and will be accountable for its delivery? What changes are needed to achieve each benefit? Who will be responsible for ensuring that each change is successfully made? And how and when will the identified changes be made?"

The BDN can be used to address the questions that materialize from constructing the benefits realization plan (Fig. 1). The BDN acts as a mechanism for mapping all the changes required to ensure expected benefits and outcomes can be delivered. As shown in Fig. 2, we need to work backwards, from right to light from the agreed investment objectives to develop a BDN [42]. In essence, we need to start by understanding the business context and fundamental drivers, as well as the investment objectives and expected benefits (Fig. 2). The alignment and mapping of business drivers to investment objectives, therefore, can provide an organization (and a project) with the impetus to achieve their desired outcomes. The motivation for adopting a digital venture will need to meet a business demand rather than being merely utilized to satisfy a technological trend that pervades the marketplace. The process of mapping enables us to chart the required "changes to structures, processes and how staff would need to work through to the new technology necessary to enable and sustain those changes" ([42]: p.3).

Within a construction organization, this does not only impact the business entity, but also impacts its project teams and supply chain.

In Fig. 2 the business changes accommodated by the BDN are both

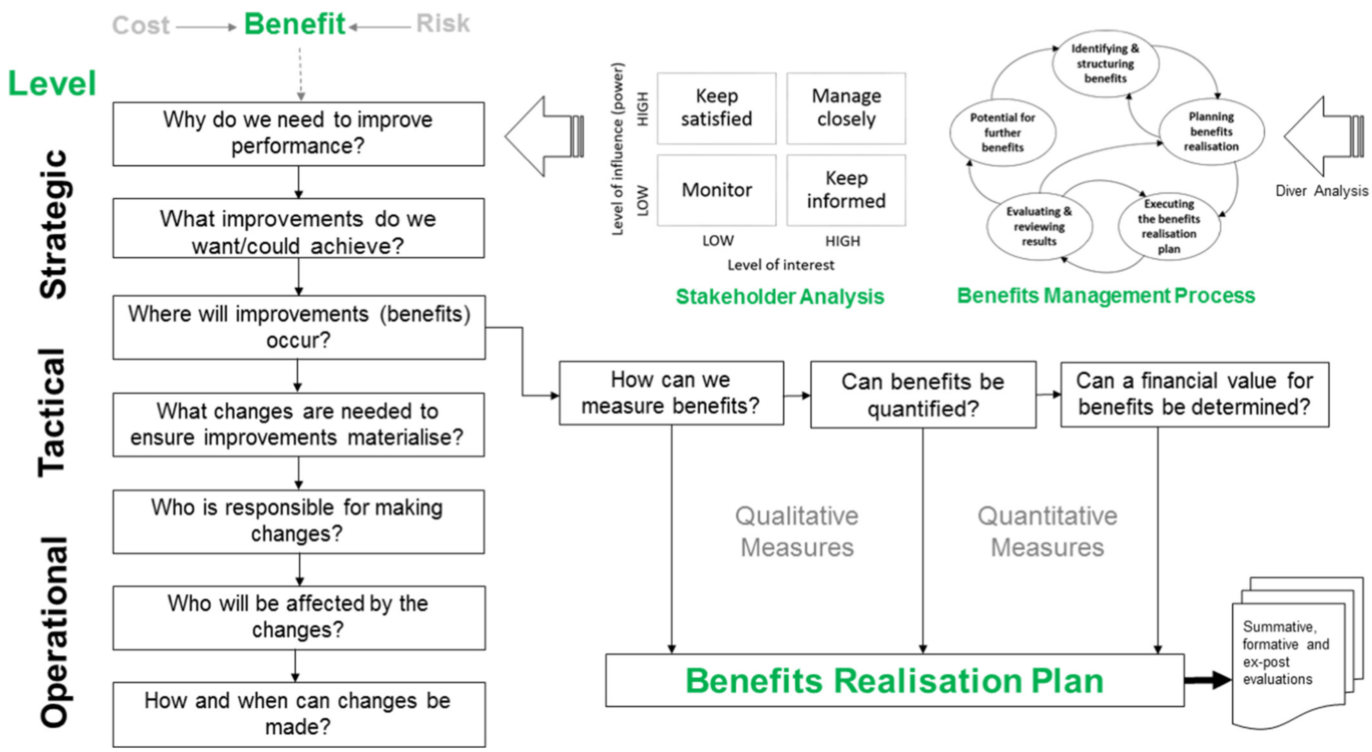

Fig. 1. Planning for benefits realization of digital technologies.
Adapted from Peppard [36].

enabling and sustaining [42]. Enabling changes are a one-off and may either form the prerequisites for creating the sustaining changes or bringing the new systems into operation [42]. Examples of such changes, identified by Peppard [42], include defining and agreeing new work practices, developing blueprints for new processes and education and training in using the new system. Sustaining changes are permanent and will affect working practices, processes and relationships, and thus will be expected to deliver benefits. After the initial construction of the BDN, measurables need to be established for the identified strategic, tactical and operational benefits (Fig. 1). Such measures will invariably be quantitative, but those of a qualitative nature may also be required (e.g. satisfaction, service quality, supply chain collaboration, and market leadership) [12]. At this juncture, we note that the BDN can be integrated with a variety of performance measurement frameworks

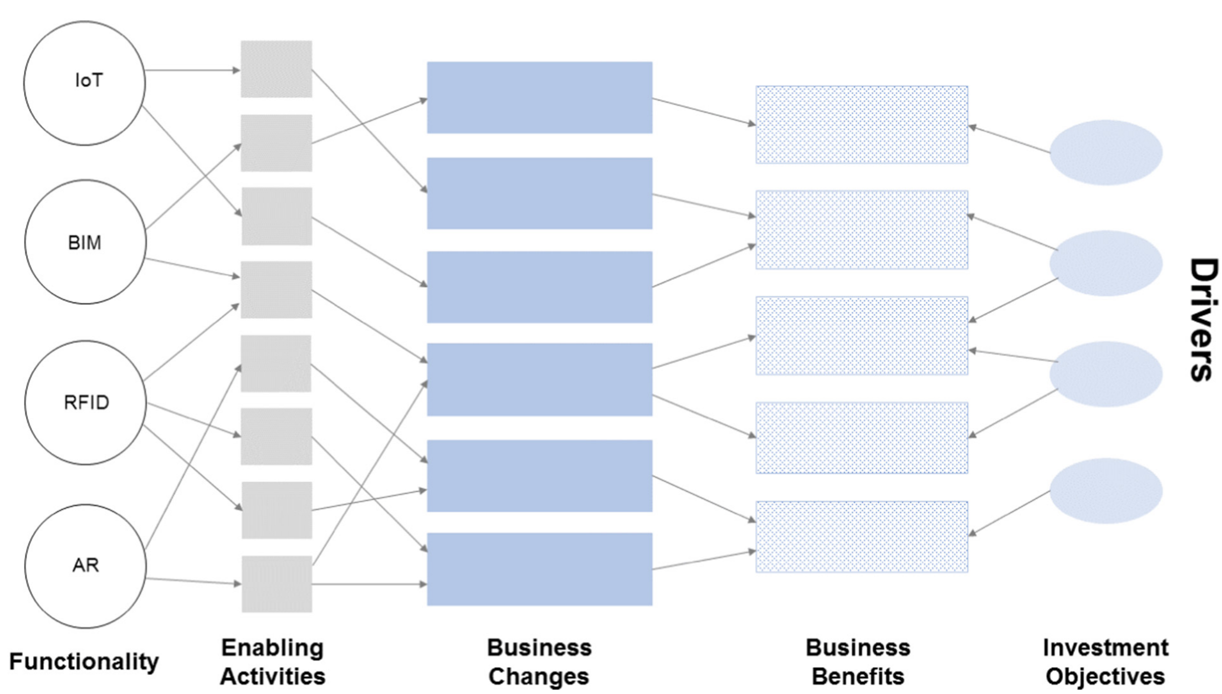

Fig. 2. The structure of a benefits dependency network.
Adapted from: Peppard [36].

such as the *Balanced Score Card* and the *Performance Prism* and thus can be used to develop a series of key performance indicators, derived from stakeholders, to monitor benefits, manage change and engender learning [41]. Assigning accountability for both achieving the desired outcome and managing the process of change is necessary in order to demonstrate a commitment to the realization of benefits [42]. Once a BDN is completed, a robust business case for investing in digital technology, juxtaposed with a viable change management plan to deliver the expected benefits, can be developed.

3. Case study

While a wide range of digital technologies are available in the marketplace, we have elected to focus on SIM to identify its drivers, business benefits, changes, enabling activities and supporting technologies in order to facilitate its implementation within organizations and projects [43–49]. Our SIM-based research has relied on the use of a case study approach, as we have sought to understand the 'why' and 'how' associated with its use in practice [43–49].

We undertook case study-based research so that specific industry problems and practical insights could be addressed and therefore enable learning and changes in practice to occur [50]. This line of inquiry enabled us to be actively engaged with practitioners within the case organizations and the projects they were delivering. The case study research approach is, therefore explanatory, as it focuses on phenomena within the context of real-life situations.

We focus our research on an instrument, electrical and safety system engineering company, which has delivered a variety of large-scale projects utilizing a SIM. A case study can contain either a single study or multiple studies – opinions vary as to how many cases are suitable for understanding a phenomenon [50]. Our case study research focused on nine projects, and has enabled generalizations on the benefits of using a digital SIM to be made, due to the occurrence of data saturation, which we refer to below. The digital SIM case studies examined the process of benefits realization from engineering design through to asset management. In two particular cases, we were directly involved with asset owners who adopted and integrated a digital SIM into their work processes and practices.

The concept of "SIM is a derivative of BIM, with 'building' being replaced by 'system' to represent the process of modelling complex connected systems" ([43]: p.156). A SIM is commonly used for modelling instrumentation and electrical systems as they are not easily described in a three-dimensional model (3D) as they do not possess geometrical properties. For example, in Fig. 3, the complexity and absence of geometrical properties for electrical cabling is presented. Thus, a SIM is a digital representation of connected systems, such as electrical instrumentation and control, power and communication, where digital objects modelled in a SIM environment have a 1:1 relationship with their physical counterparts. In Fig. 4, the relationship between a virtual and real-world object within a SIM environment is illustrated, with components, connections and functions defined and linked as they would be in the real world. As result, a SIM is able to create a *digital twin*. The Digital Asset Delivery (DAD)[5] platform is an example of software used to support the development of a SIM.

We have retrospectively constructed a BDN based on our empirical body of work which examined the benefits and use of a SIM within the context of electrical, control and instrumentation systems (ECIS). Our initial works focused on efficiency gains achieved through using a SIM to engineer and document a design when compared to traditional Computer-Aided-Design (CAD). Subsequently the focus shifted to re/constructing connected systems for the purpose of asset management. When CAD is used to design connected systems relevant information is likely to be replicated across several documents and a relationship of 1:n is established, where n is unknown. Drawings are issued in paper or PDF format and therefore, when changes are required, as is common during construction, a draughtsperson is required to amend and re-issue a revised drawing set [44]. This is a costly, time-consuming and error-prone process. The 'as-built' documentation produced and provided to asset owners at hand-over is liable to contain errors and omissions, as changes required during construction may not have been consistently reflected in the documentation. The upshot is that the 'as-builts' often do not reflect what has been installed.

3.1. Data

The data used in this research is derived from nine projects we have studied over the last six years, listed as follows:

- Iron Ore Stacker Conveyor [49,51,52];
- Floating Production Storage and Offloading Vessel [53];
- Underground Metro System [43];
- Oil Refinery [44];
- Magnetite Iron Ore Processing Plant [45];
- Geo-Thermal Plant [46];
- Cooper Mine [47];
- LNG Plant [52]; and
- Urban Rail [48].

Details for a sample of the projects studied can be found in Table 1. Triangulation formed the basis for the data collection, which predominately took place at the offices of the instrument, electrical and safety system engineering company, but also at the offices of the asset owners who participated in our studies. We used multiple research methods and/or measures to overcome problems with potential bias and validity [56].

We relied upon the use of unstructured interviews and documentary sources. In addition to the active day-to-day involvement with the participating company at their office, unstructured interviews with key personnel were also undertaken by a separate researcher who was not positioned within the office environment. This was undertaken to provide additional context and understand the nuances associated with implementing SIM as well as provide validity to the research process. Throughout the course of our study, we regularly interviewed the Managing Director, Business Development Manager and engineers, with interviews varying in length from 30 min to two hours. A similar approach was undertaken when we examined the feasibility and benefits of using a SIM for asset management [48]. We were provided with access to the drawings and contractual documents for each of the projects identified above, as well as digital models when available. Specific details of the data collated for each project can be found in our previous works, which are identified above.

4. Findings

As CAD is the primary medium used for engineering and documenting connected systems, we aimed to examine if a SIM was a better digital solution by quantifiably demonstrating its benefits. In addition, we examined whether it could be effectively used throughout a project's life-cycle, from the initial engineering of a system, to its use in operating and maintaining an asset. Based on the nine projects that were examined we have highlighted a sample of the benefits that materialized in four (Table 1). We have chosen these four projects as their benefits are similar in nature to others that came to fruition; in essence, 'benefit' saturation was identified.

The benefits of a SIM, in a similar vein to BIM, are maximized when it is utilized throughout all phases of a project's life-cycle, including management of assets [26]. As noted above, our research examined SIM during different phases of a project and we have drawn on this body of work to produce a generic BDN, which can be seen in Fig. 5. This takes

[5] For more information refer to: https://www.dad.net.au/

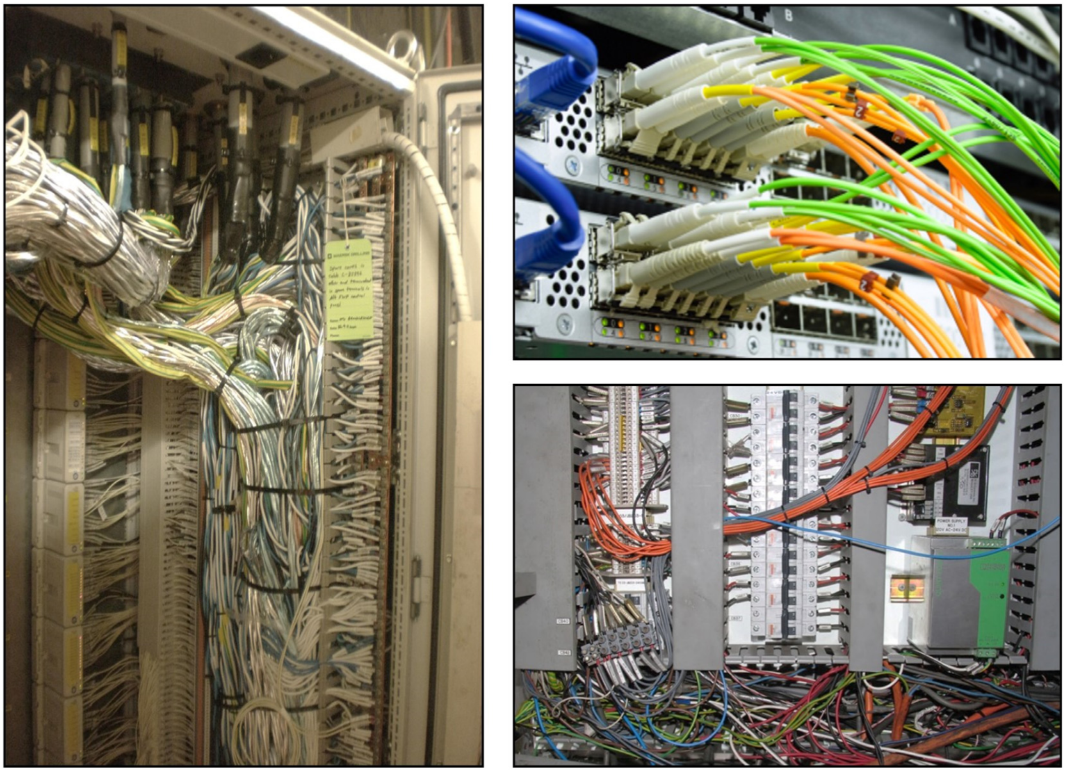

Fig. 3. System connections.

into consideration the benefits that accrued when a SIM was integrated with a sample of commonly adopted technologies over a system's life-cycle. In line with process described above to develop a BDN, we commenced the construction of Fig. 5 by determining the underlying drivers and investment objectives for using a digital SIM.

4.1. Investment objectives

Our discussions with the instrument, electrical and safety system engineering company, the organizations using SIM in their projects and with the asset owners, revealed five underlying investment objectives acted as drivers for embracing this digital technology (Fig. 5). Each of the drivers necessitates multiple business benefits. However, in Fig. 5 we have only shown an expected benefit for the purpose of simplicity as BDN can become complex and difficult to decipher. A drive to obtain a competitive advantage by reducing costs and improving productivity during the engineering and documentation process emerged as the initial forerunner for adopting a SIM when it was solely considered for this purpose/phase of a project.

Asset owners, however, took a wider perspective and not only considered the aforementioned business drivers but also risk mitigation, safety and a desire to use a digital solution to better structure and manage their information. In the case of one particular asset owner, their traditional *modus operandi* for gathering, managing and using information was adversely impacting their ability to efficiently and effectively perform their operations and maintain assets, which subsequently had a knock-on effect on the quality of rail services being provided. Most of this information was stored in paper documents that

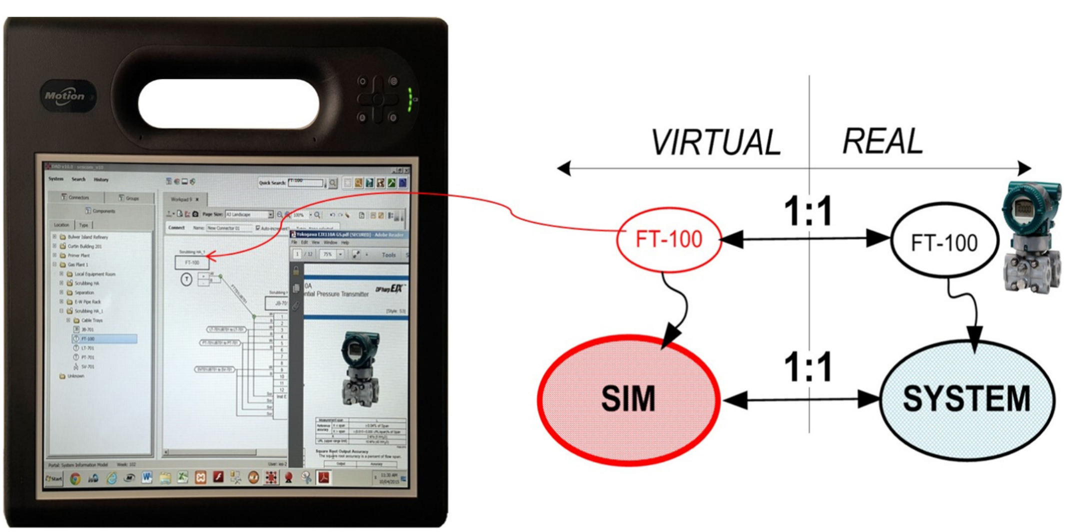

Fig. 4. A digital twin: A 1:1 relationship between virtual and real-world.

Table 1
Case examples of SIM based projects examined.

Project type	Value	Description	Level of analysis	Key findings	Benefits	Reference
Iron Ore Mine	AU$2.8 billion	There was a demand to increase production and therefore the production output of the mine from 40 million tonnes of iron in 2011 to 155 t in 2014. The increase in production result in several expansion projects. This research focused on the Stacker Conveyor, which was located a port. The port expansion cost $486 million with AU$20.76 million expended on the electrical engineering and documentation.	A set of 107 documents for Stacker Conveyor were analysed that had been created using CAD. Retrospective SIM constructed to identify problems with documentation Classification of errors and quantification of costs and information redundancy	A total of 589 cables and 469 components identified in the 107 documents A total of 449 errors and omission identified in the documents Average time to produce a single CAD drawing 40 h	Demonstrates that SIM can result in a 94.25% reduction in documentation cost and 94.99% in person-hours. Elimination of draftspersons making the engineer accountable for the engineering and documentation Time to produce a drawing in a SIM reduced to 2 h	[49,51]
			The number of times drawings were modified as a result of Request for Information (RFI) raised	A total of 618 man-hours was needed to raise and address RFIs from the 449 documents at a cost of $92,700	Use of SIM can lead to a reduction in raising and addressing RFIs by 91.67% person-hours. Improved transparency as a complete history log for an object's modification and revision can be digitally traced	[51]
Magnetite Iron Ore Processing Plant	AU$380 million	An open-pit mine 4.5 km in length and 1 km wide. The mine comprises a waste rock dump, tailings storage facility, low-grade stockpile, crushing and screening hub, magnetic separation processing plant, power station and associated infrastructure. A magnate processing plant was required. The work to be undertaken by the case study organization was to (1) document the instrumentation and electrical systems; (2) coordinate the structure of the mechanical pipping; (3) design the lighting and small power; (4) design the engineer fibre optic network; and (5) import all the reference documents into a SIM and link to relevant objects and folders. Capital expenditure for the electrical, instrumentation and controls $43.5 million	Developed 3D model for the plant that was linked to a SIM to enable the acquisition of data and visualisation of the electrical, control and instrumentation systems The link between the 3D model and SIM was undertaken using a "Waypoint" function enabling cabling to be visualized in 3D Examine the SIM in practice: design, management, construction and installation.	Functioning of drafting eliminated No paper drawings were issued during the design and construction A reduction in person-hours from an estimated 20,000 to 10,000 to manage the construction process 50% less design hours 50% less construction verification hours 80% less handover documentation QA resourcing reduced	Establishment of a collaborative digital data sharing environment Reduction in cabling wastage Improvement in installation efficiency Creation of a digital workflow – real-time reporting Reduction information redundancy On-line design review Cable schedules directly generated from SIM Improved procurement as material quantity directly available Site engineering have direct access to design via mobile devices	[45]
Rail	AU$1.86 billion	The project links an airport to the central business district. Three new stations and two tunnels, which are approx. 6 km in length 7 m wide. An existing station that was required to be extended and renovated was selected for constructing a SIM for the electrical systems as it had been designed and documented in a paper format.	Retrospectively create a SIM for a station to demonstrate asset management capabilities for an asset owner. Two sets of drawings had been created for electrical and control, and monitoring systems. A total of 30 drawings comprising layout, schematics, single lines and cable schedule were analysed SIM data to be bi-directionally linked to a 3D model of the station and integrated with Ellipse, an asset management system.	As-builts in a CAD format contained errors, omissions and information redundancy identified Inconsistencies in number and labelling components Design information such as manufacturers details and power ratings missing Calculation of cable length using Geographical Information System (GIS) Changes to work practices required by asset owner to accommodate SIM. Resistance to adopting new way of working encountered	Linking of semantic and geometric data using an Industry Foundation Class (IFC) to enable bi-directional link between a SIM and 3D model Mapping between SIM and Ellipse to enable transfer of hand-over data to be used in a structured digital format for operations and maintenance SIM can support third part GIS applications A tool for effective digital asset management where the SIM acts as consolidated point of truth	[48]

(*continued on next page*)

Table 1 (*continued*)

Project type	Value	Description	Level of analysis	Key findings	Benefits	Reference
Oil Refinery	US$27 billion	As part of an oil refinery development, port terminal and a power plant are required. The refinery covers an area of 12km^2 and its processing capacity is 400 k barrels per day of heavy and medium crudes to produce gasoline, ultra-low sulphur diesel and fuel oil.	Use of a system to undertake a constructability analysis of existing electrical systems that had been designed and documented in CAD to identify errors/omissions to determine if a SIM could be used for QA/QC purposes to ensure the reliability of the 'as-built' model.	Retrospective constructability revealed that there was a total of 4324 components and 6780 connectors.	Automatic access to detailed design information	[44]
				Revealed that over 300 km of electrical cables had been designed with inconsistent lengths	Ability to review and inspect the design for each component or cable within a digital model. Errors and omission can be identified and rectified prior to construction, reducing the likelihood of rework	
				48.6 km of external building cable were not equipped with steel wire armour	Ensures asset integrity	
				870 km of power cables did not have a protective sheath specified		
				Motors were missing and unspecified		
		An Engineering Procurement Construction Management organization was awarded an contract for the Front End Engineering Design and project management services. ECIS was one of 13 packages let.	An examination of SIM's use during process of construction.	Engineers on-site were able to immediately up-date status using cloud-based mobile devices. Information on progress instantly available to the project manager	Real-time progressing monitoring of ECIS in construction	[55]
			Project's schedule created using Oracles Primavera P6 software and used to create a digital workflow in the SIM		Progress monitored on person-hours worked	
					Activity definition and job assignment detailed at an object level in the SIM	

had been provided to them at the hand-over of their asset's construction and then placed in storage (e.g. rolls of drawings, folders of equipment information, and file folders of maintenance record).

When information was required, in order to respond to an issue that may have arisen (e.g. a breakdown or fault) or during planned maintenance, an inordinate amount of time was spent locating and verifying system information. In addition, information was often contained on several documents (e.g. drawings, data sheets, test sheets), which rendered the search burdensome and unproductive. In the case of the rail asset owner, a digital asset management system was in place, and thus the information contained within the test sheets, vendor information, or maintenance data, often needed to be manually input, which was costly, and time-consuming. This collection of drivers are common motivations for engaging in digital technology, but translating these objectives into business benefits is a challenge which requires robust business cases to be undertaken.

4.2. Business benefits

A central feature of any business case is being able to quantify expected benefits that will emerge from implementing digital technology. To quantify the productivity and cost benefits of a SIM we initially obtained 'as-built' CAD drawings for an Iron Ore Stacker Conveyor and with the assistance of engineers retrospectively constructed a digital model [49,51]. In Fig. 6, we present the key features of a SIM's structure. Here components (e.g., transmitter) are classified by their 'Type' and 'Location', and connectors (e.g. cable) by 'Type'. This enables the location of components (i.e. devices) and specific details (e.g. datasheets) to be readily accessed. Furthermore, data is never entered more than once as attributes are inherited through the location, type and group folders [55].

We constructed the SIM based on 107 CAD documents. A comparison of the cost and time to prepare these documents in CAD and SIM can be seen in Table 2. In this instance, it can be seen that a 94% cost saving and improvement in productivity are achieved from using a SIM. Similarly, a SIM was retrospectively created for a High Voltage Switchgear (HSVV) system which formed part of the Supervisory Control and Data Acquisition (SCADA) system for a Geo-Thermal plant [45]. We can see, in this case, that a saving of AU$1,376,400 could have been made. A detailed analysis of the CAD documents revealed that there was a considerable amount of information redundancy in the drawings. For example, a significant proportion of components appeared on more than ten drawings. Yet, within a SIM environment, a component only appears once within the system. In the case of a LNG domestic gas metering up-grade project it was demonstrated that by using a SIM a 95% cost saving could be achieved during the documentation process [54].

During the engineering and construction of an Iron Ore Magnetite Processing Plan, we also identified quantifiable benefits in cost and productivity from the use of SIM (Table 1). The electrical controls and instrumentation manager for the asset owner stated that the implementation of a SIM "at least halved the design man-hours compared to the traditional drawings approach. The development of the DAD construction portal containing inspection and test records (ITR's) also halved the man-hours required to complete construction verification". Other benefits identified by the asset owner include:

- no I&E drafting persons were needed;
- no formal drawings were produced; the project was paperless (Fig. 7); and
- the creation of an automatic and transparent audit trail.

In Fig. 7, we show how the SIM was linked to a 3D model to enable cabling to be visualized. A bi-directional link between the SIM and 3D model was developed to enable the location of cabling to be identified in the 3D model. As consequence, cable lengths were able to be

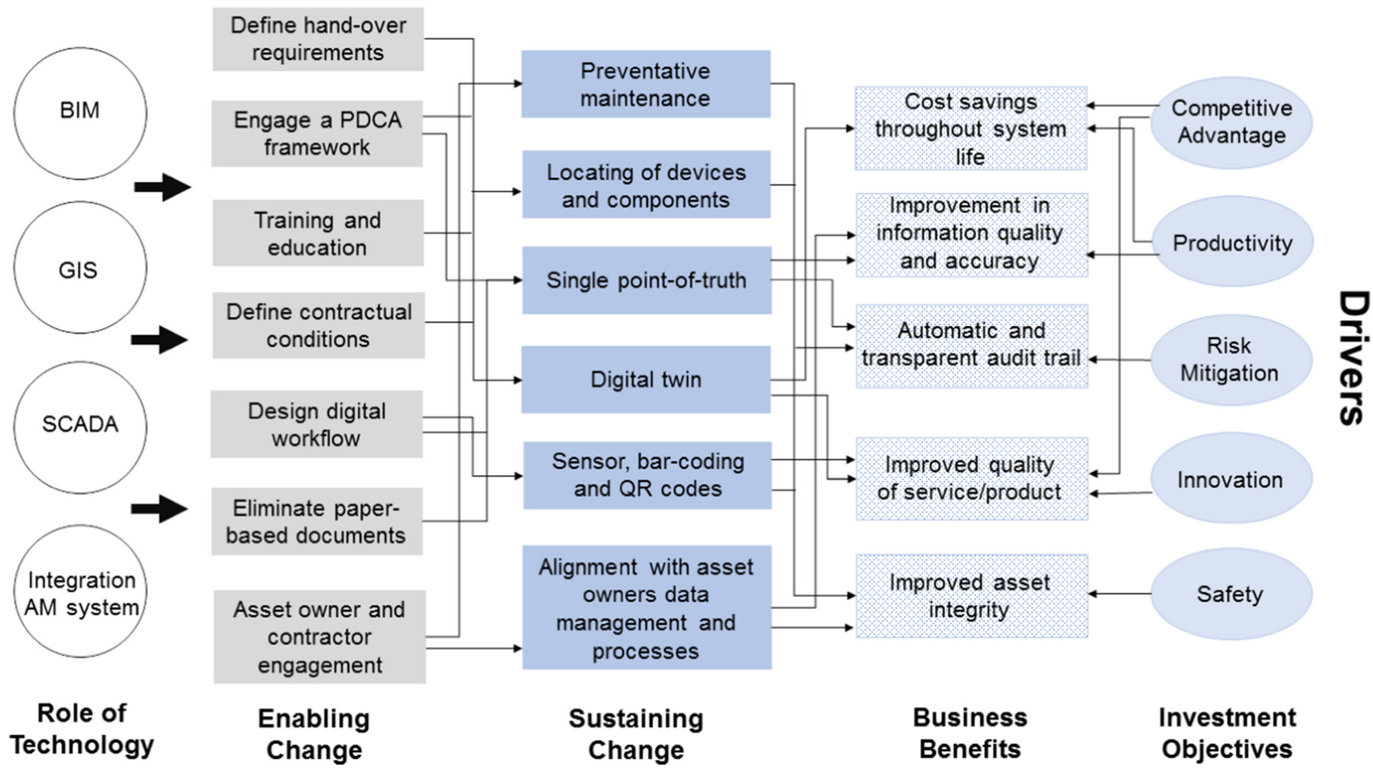

Fig. 5. Generic benefits dependency network for SIM.

calculated.

The reported SIM benefits attracted the attention of an asset owner who wanted to explore 'how' this approach could be used to support the connected systems that existed within their organization and those to be created in the future [48]. We retrospectively constructed a SIM of the electrical systems for a selected railway station that formed part of a major piece of infrastructure that was under construction. Despite recognizing the benefits of the SIM from previous studies undertaken, the asset owner needed re-assurance, within their own context, that the espoused benefits could be realized. From the 30 A3 drawings provided we identified numerous errors and conflicts.

In sum, the quality of the 'as-builts' being used as a reference for maintenance works was poor and, in part, illegible. The drawings were not regularly up-dated when modification works were carried out, or components were replaced. On production of the SIM, the asset owner recognized its immediate value, and requested us to demonstrate how a SIM could be bi-directionally linked with a BIM and integrated with their asset management system. In doing so, we are able to automate the updating of their asset management system whenever changes to the SIM occur and therefore ensure the asset's integrity. Having instantaneous access to robust information for decision-making can translate to benefits to the quality of service provided, with the time to redress faults, shutdowns, and disruptions minimized.

4.3. Enabling and sustaining change

To ensure benefits are realized mechanism need to be put in place to ensure they continue to generate business value to an asset owner. For such benefits to be sustained, however, a series of enablers for changing behaviours, work practices and processes need to be undertaken. During the course of our study, we observed several enablers of change occurring in practice. Examples include implementing a Plan-Do-Check-Act (PDCA) framework during construction (Fig. 8), continuous training and education, elimination of paper-based documents, asset owner engagement and the design of digital workflows. While critical for asset management, we did not observe the requirement for a SIM deliverable at hand-over where a performance specification had been requested for facility management. During our extensive discussions with the organizations participating in this research, the aforementioned change enablers we repeatedly identified as being core to reinforcing the changed mindset required to ensure a SIM could be effectively implemented.

In Fig. 8 the digital workflow of the SIM comprises three portals: (1) design review; (2) construction; and (3) maintenance. The PDCA framework provides a structured approach for capturing changes and ensures that a transparent audit path is created within the SIM. Specific details about how the PDCA functions within the 'construction portal' can be found in Zhou et al. [57].

Pivotal to implementing a SIM is training and education, as it requires those who engage with this digital platform to shift their mindsets from the traditional paradigm, where paper drawings are the medium for communicating information, to one that is wholly dependent on the virtual. We observed that an asset owner implementing a SIM initially encountered resistance from its in-house engineers as it required the adoption of an unfamiliar nomenclature for structuring information. The SIM was incongruous with established work practices and therefore a degree of skepticism prevailed about its legitimacy. Its legitimacy was not created and enacted from championing the need to engage with digital asset management by advocating a SIM, but by empirically identifying the failure and bottlenecks with using existing software systems that were not object-oriented in nature. The adoption of a standardized naming convention enabled SIM to be aligned with the asset owner's data management processes. Adopting such a convention reinforced their approach to preventative maintenance as accurate records of every inspection and servicing could be maintained and therefore provide an understanding of the replacement frequency for components and devices. Having in place a common data environment where information is digitally stored will not only contribute to reducing costs and improving productivity during maintenance, it will enhance the accuracy and quality of information that is collected.

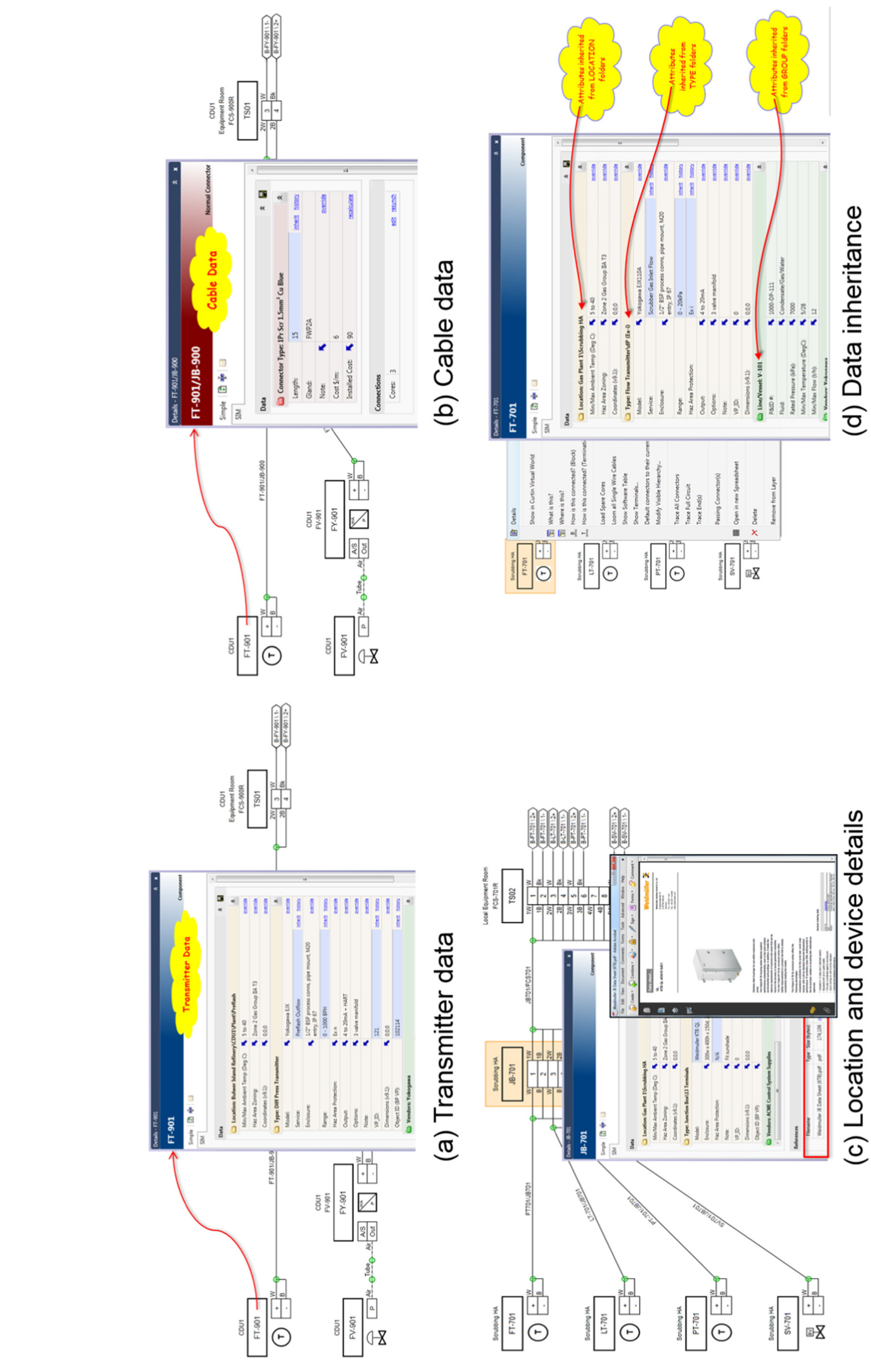

Fig. 6. Features of a SIM structure.

Table 2
CAD versus SIM: productivity and cost improvements.

Project	Method	Number of documents	Average person-hours per drawings[a]	Pay rate per hour[b] ($)	Total person-hours	Total cost ($)
Stacker conveyor	CAD	107	39.91	130	4270	555,100
	SIM	107	2	150	214	32,100
HSVV	CAD	267	39.91	130	10,680	1,388,400
	SIM	267	2	150	80	12,000
Domestic gas up-grade	CAD	716	39.91	130	28,575	37,148,22
	SIM	716	2	150	1432	214,600

[a] This assumption is based on practice.
[b] The hourly rate is based on the standard applied by the participating organization at the time the study was undertaken.

4.4. Role of technology

While SIM can be used in isolation of other technologies and provide cost and productivity benefits during engineering design and documentation (Fig. 8) its real value is realized when it used for asset management. A SIM's open application programming interface (API) enables it to be linked to a suite of technologies (e.g., BIM, GIS, and photogrammetry) and systems (e.g. SCADA) to enable a digital twin during operations and maintenance. Mobile devices can also be used to perform on-site maintenance and, via the cloud, can automatically link to a SIM enabling real-time monitoring (Fig. 9). In Fig. 10 we provide examples of technologies (e.g., BIM, GIS, and photogrammetry) and systems (e.g., SCADA) used to support the adoption of a SIM during an asset's life cycle [43–49,55].

As we have mentioned above, instrumentation and electrical systems do not possess geometry and therefore it difficult to document their location in the physical world. Linking a SIM to a building information model helps us to visualize the location of components and devices, as shown in Fig. 10. A SIM can also be linked to SCADA, and with the advances in cloud computing, IoT can be used to improve a control system's interoperability, reduce infrastructure costs and increase ease of maintenance and integration, enabling real-time reporting during the operation and maintenance of an asset [58]. A SIM can also support third-party Geographical Information Systems (GIS) as its object-oriented nature enables users to add and edit coordinate information for each modelled component [48]. The routes between connections and components can be defined and therefore the direct path of cables identified. In Fig. 10 we can see how the GIS function is used to locate a piece of plant from the SIM visually.

5. Conclusion

Digital technologies offer new ways of creating and capturing value throughout the life-cycle of an asset and can facilitate pervasive changes to practice. By enabling and subsequently sustaining change the benefits of using technology can be realized. It has been widely acknowledged that digital technologies can improve the productivity and performance of constructed facilities throughout their life, but the way in which they bring about change can be classified in three broad categories ([59]: p.4):

- *Automation*: This situation arises when an organization uses digital technology to automate existing activities or processes;
- *Extension*: In this instance, an organization uses digital technology to support new ways of conducting business that supplement rather than replacing existing processes; and
- *Transformation*: when digital technology is used to enable ways of conducting business that replace the traditional ones.

Digital technologies, such as SIM, can transform how organizations involved with the delivery and management of an asset, interact with one another and perform their operations. However, the process of adoption is complex, time-consuming and costly. If digital technologies are to effectively engender new ways of working and generate business value throughout an organization's supply-chain, then change needs to be enacted. To ensure value is being obtained organizations will need to plan and monitor their digital investments. Therefore, putting in place governance structures and processes that can be used to measure (e.g., qualitatively and quantitatively) and manage the expected benefits of a digital investment, should be a priority for an organization in order to ensure alignment with its strategy and goals.

Seldom have studies within the construction industry placed emphasis on planning, monitoring and managing the benefits that digital technologies can bring. There has been a natural assumption that the adoption of digital technologies will result in productivity improvements, but the change needed to unlock their benefits has been overlooked or misunderstood. There is a danger that if the change is not given the credence and attention that is needed, organizations involved in the design, engineering, construction and procurement of a facility as well as asset owners will be subject to the *Red Queen Effect*. In this instance, an analogy from Alice in Wonderland where the Red Queen comments while peering through the looking glass “It takes all the running you can do to keep in the same place”, can be made with reference to implementing digital technology as, without change, improvements will go unrealized. The upshot is that organizations will become unproductive and uncompetitive.

Within construction, there has been increasing emphasis placed on ‘why’ digital technologies needs to be embraced with limited attention focusing on ‘how’ expected benefits can be realized. In making headway to address this void, we have referred to our body of work which examined the benefits of SIM for electrical, control and instrumentation systems. Empirical findings derived from nine projects that examined the efficiency gains and benefits of using a digital SIM, from an engineering to asset management perspective, were used to develop a generic BDN. We identified the drivers of a SIM, it's business benefits, the enabling and sustaining activities and supporting technologies that can be used to facilitate its implementation by organizations and asset owners. The resultant BDN enabled investment objectives and their resulting benefits (the ends) to be linked in a structured manner with an organization's capabilities (the ways) and the changes required (the means) to ensure they are realized.

While digital technologies such as a SIM provide opportunities to generate business value, they may also become a financial ‘black hole’ for organizations. Adoption of digital technologies should be need and demand driven, but often organizations are confronted with, and pressurized (e.g., by clients) to, adopt the latest fads based on superficial or spurious claims of unrealistic benefits. Our research makes headway toward curbing this problem, though within the context of a digital SIM, as it empirically demonstrates realistic benefits, grounded in practice, that emerge from implementing a whole life-cycle, object-oriented SIM for ECIS. The main contributions of our research are twofold:

1. Our findings have repeatedly demonstrated that a SIM provides significant productivity and cost improvements for ECIS with benefits realized by engineers, contractors and asset owners. There is a

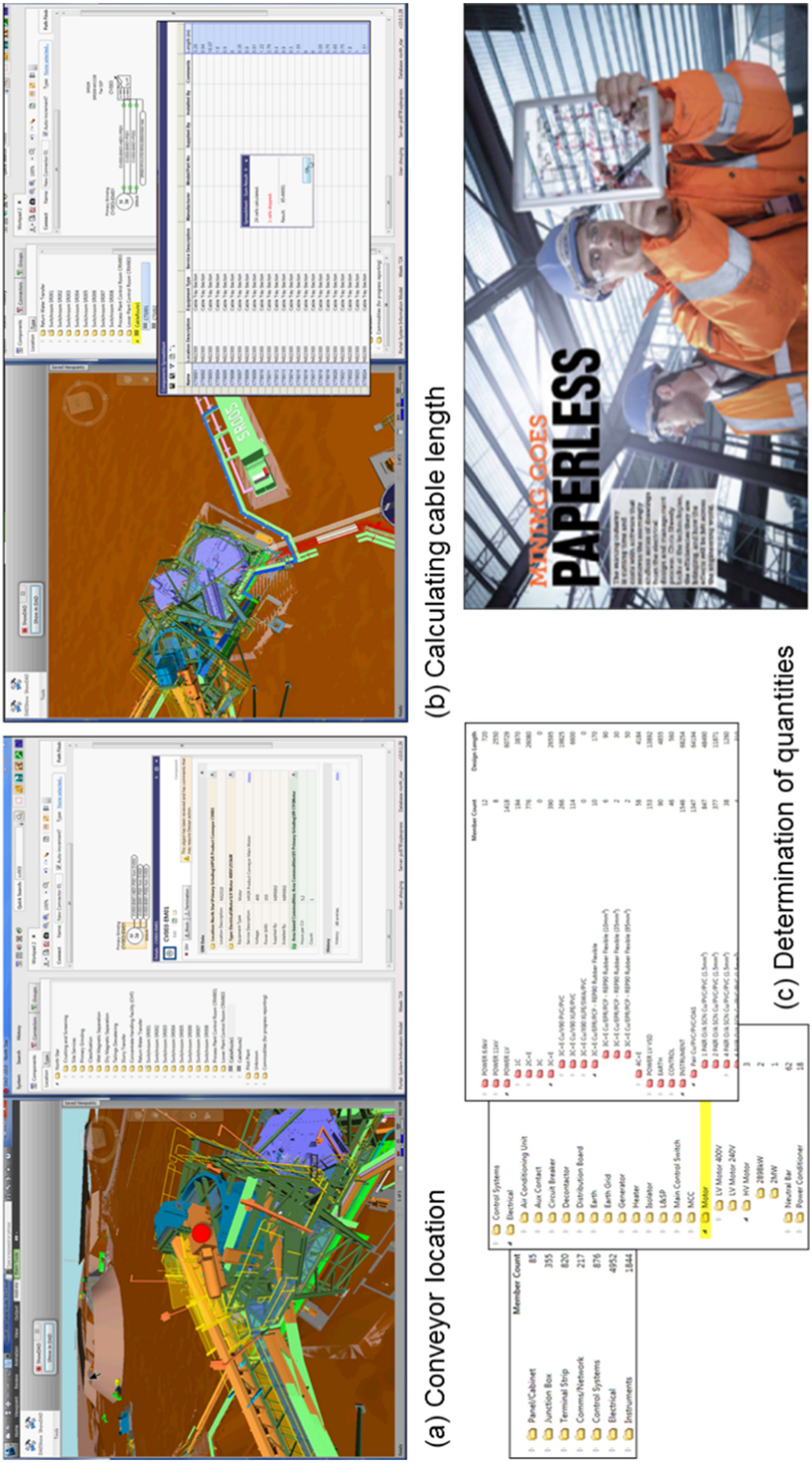

Fig. 7. Magnetite iron ore processing plant.

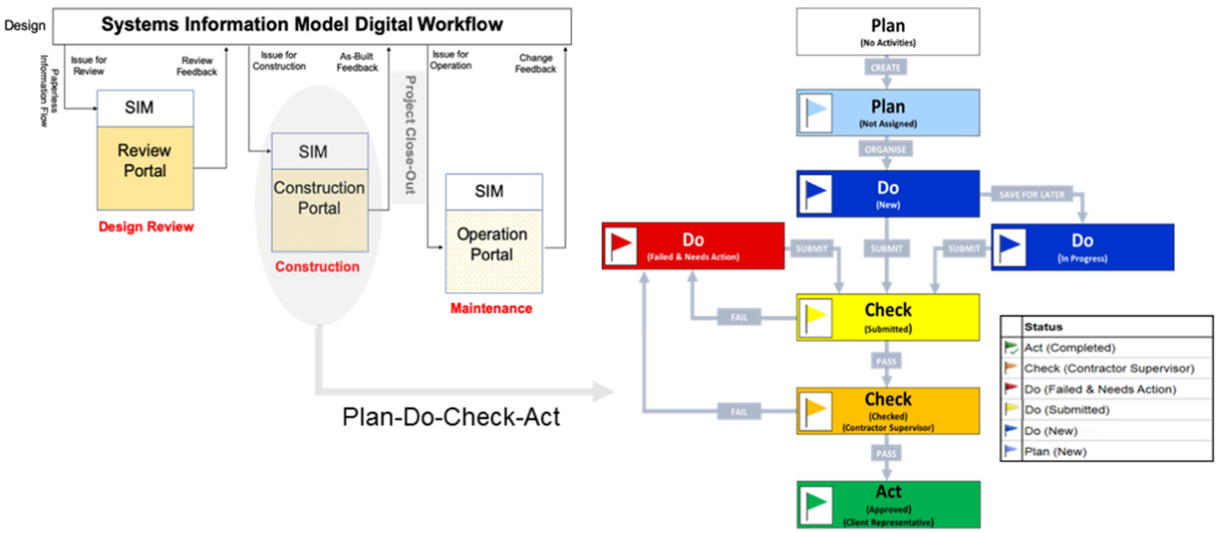

Fig. 8. Plan-Do-Check-Act framework for construction.

paucity of studies substantiate the use of digital technologies in practice. Thus, we provide the impetus for research to focus on engaging lines of inquiry that can provide organizations with confidence that benefits can be realized from implementing digital technologies. We would like to reiterate, however, that a change management strategy will also need to be simultaneously embraced. The change management associated with technology adoption in construction is an area that has received limited attention. We therefore suggest that future research is needed to examine 'how' change management can be enacted to realize the benefits of digital technologies at an organizational and project level.

2. The generic BDN visually structures the multiple cause-effect relationships into capabilities, changes and benefits. It provides organizations with the knowledge and understanding needed to acquire the benefits that can accrue from making strides toward the creation of a digital twin. A SIM has provided several organizations with the ability to construct and use a digital twin of their ECIS. Future research is required to examine how this can be integrated and coupled with an assets wider eco-system, within which ECIS exist.

To this end, the insights and experiences that have emerged from our research provide a frame of reference for construction organizations and asset owners to navigate the benefits realization and change management process, which can be used to ensure that their investments in digital technology can effectively respond to business drivers and generate value.

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Fig. 9. Mobile devices using SIM.

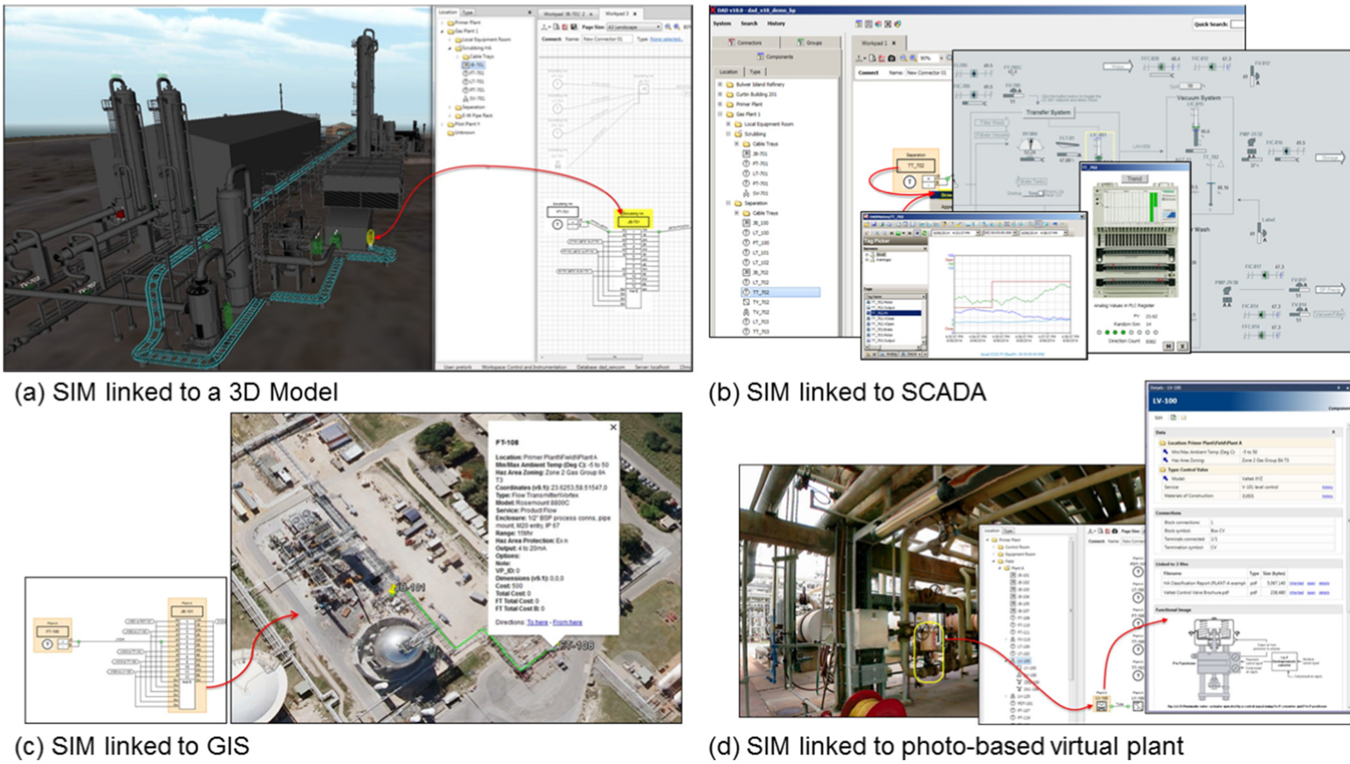

Fig. 10. Linking of SIM to technologies and systems.

experiences and insights with using a SIM. Without the financial support of the Australian Research Council (DP130103018 and DP160102882), parts of the research reported herein would not have been able to be undertaken.

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