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Abstract

The demand for and on data centres continue to pose several power, cooling, and performance constraints associated with environmental and economic inefficiency. Sensor Information Systems (SIS) is one of the best practices for addressing these constraints. This study investigates the assimilation of SIS in data centres. Based on the empirical data gathered from five case studies of Australian data centres, the paper evaluates the current state of SIS utilisation. The results indicate that the utilisation and assimilation of SIS in data centres is very limited. A conceptual framework and several theoretical propositions rooted in the TOE model are proposed to explicate the conditions that influence SIS assimilation. A number of factors including perceived SIS complexity, affordability, reliability and compatibility, the infrastructure characteristics, the age and the type of data centres, green IT strategic orientation, managers' knowledge and expertise of sensor technology, governance and regulatory requirements have been identified as antecedents for the successful SIS assimilation in data centres.

Keywords: Sensor Information System, IS Assimilation Model, Data Centre Sustainability Green IT/IS

1. Introduction

The role and impact of information technology (IT) on environmental sustainability is attracting the attention of policy makers, practitioners and researchers alike (Greenberg et al., 2006; EPA, 2007). One of the areas of IT where environmental sustainability is becoming important is Data Centres (Schulz, 2009). Data Centres refer to the business facilities that contain large information and communication technology (ICT) infrastructure platform (ICTP), and, cooling and power delivery equipments (Critical Site Support Platform-CSSP) to store, process, and exchange digital data and information. A data centre represents an area with a large concentration of electronic equipment and power density within a limited space (Lefurgy et al., 2003). It is one of the largest energy consumers, accounting for approximately 1% of total global energy use (Koomey, 2008). While the demand for and on data centres continues to increase, these digital 'powerhouses' are faced with several power, cooling, and performance constraints (Schulz, 2009). Improving the energy efficiency and environmental performance of data centres is therefore at the forefront of organisations' actions in 'greening' their IT (Daim et al., 2009).

A number of practices, methods and technologies can be employed to convert data centre operations into sustainable practices (Baird and Mohseni, 2008). Of these, Gartner has promoted 'sensorisation', as one of the 11 best practices (Gartner, 2008). Sensorisation refers to the wide application of sensors (electronic devices that detect and observe their surrounding environment) (Meijer, 2008) and sensor information systems (SIS). The use of sensors to monitor temperature, heat and security is an old practice in data centres (Davis et al., 2006). Nevertheless, it is only recently that these sensors have been integrated into information systems (IS) (Marwah et al., 2009) to automate data centre

management functions, inform decision making, and transform data centres to improve their environmental and operational sustainability. Such SIS can be considered as an example of green IS (Watson et al., 2010) as they can provide effective solutions to reduce the energy consumption and the environmental impact of data centres. A review of the IS research shows that there is a dearth of theory driven empirical research on the utilisation of SIS in data centres and the factors that explain variations in applying SIS. Understanding the factors that facilitate or inhibit the utilisation of SIS is critical to help data centres to leverage the advantages of SIS.

This paper empirically examines the utilisation of SIS in five Australian data centres and identifies the antecedents to the assimilation of SIS. Its contributions to IS research lies in showing how IS integrated with sensors can help to tackle some of the environmental and operational challenges of data centres. The paper adds to the emerging body of knowledge on green IS and IT. It also contributes to data centre management practices as it reports how SIS can be integrated into the ICTP and CSSP. The rest of the paper is organised as follows. Section two presents a background review of SIS and the technology adoption and assimilation theories that informed the case studies. This is followed by the research method. Section four describes the results of five case studies which led to the development of a number of propositions and an integrated SBIS assimilation framework. The paper concludes with some observations.

2. Background

2.1. SIS and Data Centres

A sensor is a small electronic chip that is capable of converting a physical phenomenon such as heat, light, sound, or motion into electrical or other signals (Zhao and Guibas, 2004). Sensors detect and identify their surrounding environments and/or objects within that environment and communicate the information to other systems which can then process the information in various ways (Meijer, 2008). Thus, sensors can significantly enhance the three generic functions of IS, that is, *automation, informatisation, and transformation* (Zuboff, 1988). The convergence between sensors and IS can result in an enhanced sense-aware IS platform referred to as SIS. SIS can be defined as any IS that utilise sensor(s) which are directly or indirectly connected to one or more sensors or sensor network in order to automate, inform and/or transform a given task or process or appliance. Examples of SIS are Building Management Systems (BMS), Congestion Management Systems, Geographic IS and Environmental Monitoring IS.

The advantages of SIS in IT infrastructure management include early failure diagnosis, automation of quality monitoring, and optimisation of processes and resources (Meijer, 2008). Such advantages of SIS make their utilisation ideal in various domains, especially for the purpose of energy conservation (Garg and Bansal, 2000; Watson et al., 2010). For instance, an SIS connected with lighting and heat, ventilation and cooling systems of a building can enhance the exploitation of natural forms of lights, ventilation and radiation, and reduce the reliance on fossil fuel generated electricity power. Such applications of SIS can yield a 25–50 per cent energy saving (Garg and Bansal, 2000). This implies that, data centres, as a significant energy consumers can economically benefit from the use of SIS.

Data centres are one of the areas that have attracted practitioners' and researchers' endeavours to address eco-sustainability issues associated with IT (Schulz, 2009). Business and other institutions' demand for large volume of data processing and storage capacity is increasing (Lefurgy et al., 2003, Loper and Parr, 2007). In general, the increase in data centres' volume is usually associated with an increase in energy consumption, energy related CO^2 emissions (EPA, 2007). Several consultants, regulatory institutions and researchers have proposed various best practices to help data centres enhance both their operational efficiency and environmental footprint (Greenberg et al., 2006; EPA, 2007; Gartner, 2008). Out of which, the use of SIS is of particular interest to this paper. The use of SIS for automating the operations of data centres can significantly improve the operational and energy performance and environmental footprint of data centres (Gartner, 2008). For instance, SIS can be

used to monitor the occupancy of a data centre facility as well as the temperature, airflow and water flow of cooling systems (Loper and Parr, 2007). Smart integration of different sensors with other IS platforms can optimise air flow management in data centres (Marwah et al., 2009). Although SIS offers opportunities to address the operational, economic and environmental challenges of data centres a number of factors can influence the extent of SIS assimilation. The following section reviews background theories of technology assimilation and develops the research framework that guided the case study research.

2.2. Theories of Technology Assimilation

Technology assimilation refers to the acquisition, full utilisation, and institutionalisation of a technology (Meyer and Goes, 1988). While the adoption of innovation implies the implementation and initial success of a system (Damanpour, 1991), the assimilation of technologies implies the absorption of a technology into the routines of an organisation or individual. It reflects the 'how', and 'to what extent' a technology is utilised within organisational frameworks. Assimilation of technologies helps organisations to leverage the advantages of using IT in their business activities and strategies (Armstrong and Sambamurthy, 1999). However, the "assimilation" construct has been defined in the IS literature in different ways. A sample review of the IS literature (i.e. McGowan and Madey, 1998; Zhu et al., 2006; Liang et al., 2007) reveals most researchers draw from Massetti and Zmud's (1996) four facets of assimilation including *volume, diversity, breadth, and depth*. Volume represents the percentage of an organisation's processes that are handled through a system. Diversity refers to the variety of business functions that are performed routinely through a system. Breadth represents the extent to which an organisation has used a technology to conduct routine functions and depth refers to the degree of a system's functionalities that has been established in performing the business processes (Massetti and Zmud, 1996).

Previous IS research on the assimilation of technology has identified a number of factors that could influence the volume, diversity, depth and breadth of IS use. These factors have been researched from technological perspective, organisational perspective (Roger, 1983), environmental perspective (Tornatzky and Fleischer, 1990), and institutional perspective (DiMaggio and Powel, 1983). The technology-organisation-environment (TOE) framework (Tornatzky and Fleischer, 1990) provides a generic foundation that integrates the technology, organisational, environmental and institutional perspectives to understand the factors that could affect the assimilation of technologies in data centres.

In TOE, *the technological context* refers to the characteristics of technology innovation such as relative advantages; *the organizational context* refers to firms' measurable characteristics such as size, scope and resource availability; and *the environmental context* refers to the context in which an organisation performs its business such as industry, market, and government regulation (Tornatzky and Fleischer, 1990). The TOE has been used to study both complex and evolving technologies such as object-oriented technology (Ihlsoon and Young-Gul, 2001), e-business (Zhu et al., 2006) and ERP (Kouki et al., 2010). The generic nature of the TOE makes it suitable to study different types of technology innovation. Thus it is useful to be applied as a foundation for investigating SIS assimilation. Although TOE based models have used the 'environmental' context, the context was narrowly defined and excludes the natural environment. The growing importance of natural environment implies that the use or misuse of technology might be influenced by natural environmental considerations (Hart, 1997). The adoption and use of IS can often be influenced by environmental considerations (Chen et al., 2008), especially in data centres where considerable environmental footprint is present (Schulz, 2009). Such considerations would likely create either facilitating or inhibiting conditions for the assimilation of SIS in data centres. Thus, this research incorporates the natural environmental consideration into the TOE. The proposed conceptual framework is depicted in figure1.
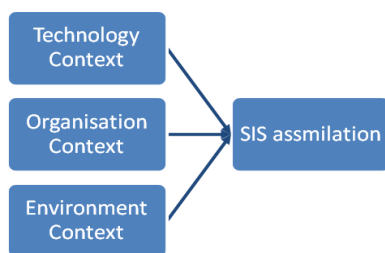
Figure 1.   A proposed framework for SIS assimilation in the data centres.

3.   Research Method

The research is conducted based on, case studies of five Australian data centres during the first half of 2010. As stated by Eisenhardt (1989, p. 533), case studies help to understand the dynamics present either within a single or multiple settings. A case study method can be used to answer research questions such as 'why' and 'how', and to analyse an emerging phenomenon (Yin, 2003), and as such is relevant for the study of SIS use in data centres. Conducting cases studies based entirely on a few interviews with key informants is a well-accepted method commonly used in the early stage of research on particular phenomenon (Myers, 2009; Yin, 2003). Therefore five cases studies were assumed to be adequate for the purpose of this research. The data centres were identified using snowballing sampling techniques based on contacts developed through attendance of data centre workshops and conferences. The main data collection method was face-to-face interviews with data centre managers. Except for one, all interviews were tape recorded and the sessions transcribed before the data were analysed. Four of the data centres kindly offered us a tour of their facilities. To enhance the validity of the answers, the findings of each interview were verified by the participants at the end of each interview session. Furthermore, to ensure consistency and reliability, structured interview guides were used. The data were then analysed using content analysis techniques. A summary description of the five data centres is presented in Table 1.

Case No.	1	2	3	4	5
Industry	Education	Education	IT	Telecommunication	IT
DC type	Corporate	Corporate	Co-location + Managed	Co-location	Co-location
Targeted business	Internal clients	Internal clients	Large, medium and small firms.	Large, medium and small firms.	Public enterprises and agencies.
Age of the facility	Old	Old	New	Old	New

Table 1.   Description of the data centres used in the sample

4.   Findings and Discussion

Although all the five cases have installed sensors and adopted SIS, they differ slightly in the assimilation of SIS. Based on Massetti and Zmud's (1996) facets of assimilation, we have explored the volume, diversity and intensity (breadth and depth) of SIS summarized as in Table 2.

In terms of volume, there can be three indicators for evaluating the volume of SIS - the number of installed sensors, the types of sensors and the type of SIS. The number of installed sensors refers to a headcount of active sensors. The sensor type refers to the variety of sensors such as environmental sensors (e.g. temperature, air pressure, and humidity), magnetic sensors (e.g. motion) and occupancy sensors (e.g. detect the room vacancy). The SIS type refers to the unique features and functions of a SIS used in a data centre. The findings indicate that except one (case five) all the other data centres

have relatively comparable SIS volume. Notably, in all cases, the common SIS is a BMS. In one case (case five), in addition to the BMS, other integrated SIS such as InfraStruXure Central, InfraStruXure Management and InfraStruXure Capacity developed by APCC are implemented. According to the manager of case five, the incorporation of these SISs is necessary because the advanced capability of these specialised systems provide sophisticated monitoring and management tool set. The SIS in case five has an executive blackboard that enables managers to review, and manage their entire infrastructure. For instance, it automates and transforms the cooling infrastructure into a "super intelligent platform" by synchronising the outside and inside temperature and shifting the load between gas and free-air cooling systems. The system helps the managers to adjust the cooling capacity based on the changing temperature, workload and equipment conditions.

In terms of diversity, four areas of SIS application has been identified- *facility, cooling, power and computing resources management*. Facility management refers to the security, safety, lighting and auxiliary systems of the data centre physical building. Cooling management refers to internal climate control in the data centres including Computer Room Air Conditioning (CRAC), Heating, Ventilation, and Air Conditioning (HVAC) and Water-Chillier plants. Power management refers the delivery and distribution of primary and secondary power systems in the data centres including Power Distribution Units (PDU), Sswitchboards, Power Generators and Uninterruptable Power Supply (UPS). Computing resources management refers to the IT equipment used for performing the computation functions in the data centres including servers, network, storage, peripherals, and back up devices. The findings indicate that while SIS are mostly applied in facility, cooling and power management, they are less used in computing resources management. For example, in reference to facility, cooling and power management, the manager of case one stated, "*I can't imagine a data centre that wouldn't make use of sensors.*" However there are differences in terms of the granularity of SIS use in cooling and power management. While case one applied SIS for monitoring energy consumption at the entire data centre level, cases two, three and four have more detailed applications that measure the energy at the CRACs levels. Case five, in addition to these applications, extends it to cover the energy measurement of the rack. SIS application in case five includes reading the measurement from PDUs, providing a wider view and an accurate measurement for the power activities of the entire data centre. SIS use for computing resources management appears to be very rare. Case one, is the only data centre that have applied narrow SIS use for IT assets management limited only to the monitoring function and with no additional automated task beyond that. This finding contradicts the potential capabilities of SIS reported in theoretical and experimental research. An interview commented that "*It is conceivable, but in my view, it is a very long shot*".

In terms of intensity, the interviews have identified five important functions of the data centre facility, cooling, power and computing resources management**.** These are monitoring, analysing, reporting, recommending and controlling. These functions constitute the functional hierarchy of SIS.

"Monitoring" refers to the process of observing the behaviour and status of the facility, cooling, power and ICT resources within the data centre without performing additional tasks. In this function the system operates in the background and the data centre operator can access the system anytime and view the real-time or historical readings when desired. "Analysing" refer to the process of automatically diagnosing the behaviour of monitored data centre objects, and performing certain checks and evaluations in order to understand the cause and effect of any changes in the behaviour. This function represents the data processing phase and uses the real-time and historical data of the monitored object together with some predefined parameters as inputs for processing. "Reporting" involves the process of generating meaningful information about important and/or time sensitive change in the behaviour of an object (i.e. an increase in the temperature) and automatically alert the operator (decision-maker) through the appropriate method of communication (i.e. Short Message Service (SMS) in order to undertake an immediate action. "Recommending" refers to the process of identifying the needs and determining the solutions to a particular systems failure or problems based on the analysis in order to help the data centre operator in the decision-making process. "Controlling" refers to the process of executing the decision-making process in respect to the data centre business

functions with the substitution of human efforts. This function utilises the process of recommendation to automatically perform actions such as triggering or activating equipment or process.

In three out of the five cases (cases one, two and three), the application intensity of SIS was more or less the same. These data centres use SIS to monitor, analysis, diagnose, report and in less occasions to recommend and control the different processes of the cooling infrastructure management. Case four extends this and uses its SIS to control shifting the load between chillers. Case five shows relatively higher utilisation of SIS as it had invested in customised BMS together with specialised SIS. This has allowed the transformation of most of the infrastructure into a smart platform. According to the manager of case five, "*We use [our SIS] to monitor the temperature and humidity of the room and racks (front to back), accesses to and security of the rack doors, airflow of the cooling system, water flow, power generators, the status of the batteries, the status and power activity of the UPS, power into/out of the main switchboard, the sub-distribution board, the power draw on each rail and all phases of power delivery to each rack and each UPS...and from an automation perspective...all of those tasks are fully automated...to the point we can remotely start generators and things from home*."

Although all the five cases have adopted SIS, they differ in the assimilation of SIS, as well as in their plans to extend the current level of assimilation. We have explored some of the factors that explain both the current trends and future plans shown as in Table 2. These factors can generally be classified into technological, data centre particulars, organisational and environmental factors.

Case No.	1	2	3	4	5
SIS volume					
Number of Sensors	5-10	N/G*	30+	5-10	60+
Types of Sensors	5	5	5	3	6
SIS Type	1	1	1	1	4
SIS diversity					
Facility Management	Yes	Yes	Yes	Yes	Yes
Cooling Management	Yes	Yes	Yes	Yes	Yes
Power Management	Yes	Yes	Yes	Yes	Yes
Computing Management	Yes	No	No	No	N/A*
SIS intensity					
Monitor	Medium	Medium	Medium	Medium	High
Analyse & Diagnose	Low	Medium	Low	Medium	High
Report & Alert	Medium	Medium	Medium	High	High
Recommend	Low	Low	Low	Low	Medium
Control	Low	Low	Low	Medium	Medium
Key Factors for Assimilation					
Technological			✓		
Perceived SIS Complexity	✓				
SIS Affordability		✓	✓	✓	
Perceived Reliability	✓	✓	✓	✓	✓
SIS Compatibility			✓		
Data Centre Particular					
Infrastructure Requirement	✓	✓	✓	✓	✓
Data Centre Age	✓	✓	✓	✓	✓
Data Centre Type			✓	✓	✓
Organisational		✓			✓
Green IT Policy		✓			✓
SIS Know-how of Manager			✓		
Data Centre Governance		✓			✓
Environmental					
Regulatory Requirement	✓	✓	✓	✓	✓

*NG= not given, N/A= not applicable

Table 2.   *A summary of the key findings of SIS assimilation in the five data centres*

Technological Factors. Based on the observation, perceived SIS complexity, perceived affordability, perceived reliability and SIS compatibility are identified as the technological factors that influence the volume, diversity, and intensity of SIS. The perceived complexity of broadening and deepening the use of SIS beyond the traditional application is found in some cases to have a negative effect on the diversity and intensity of SIS. The managers of cases one and three have reported complexity as a number one issue not to extend the use of SIS beyond the facility and cooling management. The manager of case one commented that every data centre has a unique equipment and configurations and needs to be handled on a case by case basis which makes it complex to integrate SIS. Case three's manager opines that *"extending the intensity of our existing SIS for performing advanced power management would push the systems beyond their capability and could compromise the platform or create unintended outcome"*. He continued that all the IT assets hosted in the facility are owned by external clients which makes it complex for integrating IT asset management together with the other management areas using one comprehensive SIS in the data centre. On the other hand, the managers of case two and five have a broader understanding of sensor developments and advanced SIS applications with a lower perception of complexity. This suggests that the perception of complexity might relate to SIS know-how of the manager.

In four out of the five cases, the perceived SIS cost was one of the significant factors that affect wider SIS use. The manager of case two commented, *"We can have SIS that could do thermal dynamics and show what each rack is consuming, and turn your air conditioning up and down. We haven't gone down that path, it's just too expensive."* The case four manager added, *"In order to install these systems, we would need to replace all our PDUs, power boards, and then interface it into the system. I looked at the cost: that was going to be $300,000 to replace all the power systems, buy the software and incorporate it. It's just not going to happen."* All respondents agreed that the decision to buy new SIS always involves buying additional products/systems or changing the existing ones, due to compatibility issues.

The case study further suggests that the perceived SIS reliability influence SIS intensity. In cases two, three and four, the managers perceived lower reliability of SIS for automating the performance of some of the tasks especially within the areas of power management and IT asset management. The case two manager stated, *"We have to do the tasks manually because we don't really want the system to do it automatically...We want to find out whether the sensor is faulty...If suddenly all your sensors go off, we've got a major problem in our room."* It seems that these three cases were uneasy to use SIS for managing and automating mission critical facilities. However, this was not the case for the managers of cases four and five. This variation is due to the actual realisation of SIS benefits, infrastructure compatibility, and the accumulated experience of use. In other words, a greater level of actual SIS utilisation led to a better perception of its reliability.

Only case five has integrated different SIS within air/cooling and power platforms. Although case one has no integration, the manager stated, *"There will be no problems if we want to integrate it; it could be integrated because the output of these sensor are quite flexible."* However, the manager of case five argues that *"Although others might say they don't want to integrate, they actually can't...because their infrastructure is not compatible."* This is because the majority rely on the BMS to do all of the jobs. In addition, most of the computing and SIS products are not standardised in terms of interoperability. *"We acquire our infrastructure from one vendor, so all our platforms are compatible,"* says the case five manager. This might explain why case five has achieved better SIS integration. However, the manager of case two argues that *"the problem with this strategy is that you're being hooked into one vendor."* The case three manager stated, *"All our racks are sensors-based, but we do not utilise them practically...however, if our client wanted to, then we would."* This suggests that higher SIS compatibility with existing infrastructure is positively associated with the level of SIS assimilation. Based on the above discussion the following propositions can be made

Proposition 1: While the compatibility of SIS with existing data centre infrastructure and the perception towards SIS reliability facilitates the assimilation of SIS, affordability and complexity inhibit the extent of SIS assimilation

Organisational Factors. The study has identified some organisational factors that influence the assimilation of SIS. The most important ones are green IT policy, SIS know-how of manager, and data centre governance. Green IT strategic orientation refers to the existence of green IT policy in data centres, or within the overall organisation and influences the level of SIS use. Only case five had a green IT policy and it has achieved the best state of SIS utilisation. Case two, which had an active energy efficiency initiative including the installation of energy meters, purchase of mostly efficient systems, and retirement of inefficient systems, to improve the energy efficiency by 20% within the next three years, has recorded a high level of willingness to assimilate SIS in the very near future. The manager of case two says, "*There's a sensor-based system for power management called Energy Wise that's done by CISCO and we're looking at that at the moment.*" This suggests that higher level of SIS assimilation can be positively associated with existence of green policy and energy efficiency initiatives.

The SIS know-how of managers was found to influence their willingness to extend the level of SIS use. Though case three can be ranked as the second best position in infrastructure readiness for assimilating SIS, the data centre manager of case three has a lower level of knowledge about SIS features and capabilities, which was also associated with lower level of SIS use. The managers of cases two and five had good understanding of sensor capability and development of SIS platforms in the market. The manager of case five commented "*You would be talking to a lot of data centre operators and they don't even know what we are talking about here...For them, it is just a big black hole that they keep pumping the power into.*" This suggests that managers' know-how of SIS is positively associated with their ability to determine the best SIS volume that need to be acquired, the diversity of functions that can be supported, and the level of SIS intensity.

The data centre managers of cases two and five have reported a relationship between the type and intensity of SIS, and the responsibility and accountability of data centre managers for energy efficiency. "*The university is looking very seriously to the power consumption of our data centre and started to install power meters [sensor based] in all buildings... so we[data centre] have got to look at ways for reducing the energy consumption... our goal is to get that as low as possible*", says the manger of case two. Further, the clients that case five hosts have demanded the data centre to maintain energy transparency in its operations, which in turn drives case five to assimilate SIS. This suggests that data centres governance with respect to the accountability and responsibility of energy efficient and transparent operations is positively associated with the level of SIS assimilation. Thus, the following propositions can be made

Proposition 2: The existence of green IT policy, the level of SIS know-how of managers, and the existence data centre governance strategy are positively associated with the volume, diversity and intensity of SIS in the data centre.

Environmental Factors. The regulatory environment within which data centres operate and the requirements for regulatory compliance can foster the assimilation of technologies. In such conditions, regulatory environment can influence the volume, diversity, intensity of SIS. All respondents stated that the compliance to the regulatory requirement such as emission reporting will push the entire data centre industry to opt on SIS in the near future. Whereas case five has already applied SIS for this purpose, case two are looking to utilise SIS for the same objective in the very near future. This support the proposition that regulatory requirements might directly or indirectly lead to an accelerated and higher SIS assimilation in the data centres. This leads to the following proposition.

Proposition 3: Data centres operating in highly regulated and environmentally-aware regimes are more likely to archive higher level of SIS volume, diversity and intensity

Data Centres Particulars, in addition to the TOE antecedents, the study has discovered that the characteristics of the data centre infrastructure, the age of data centre and the type of data centres are additional factors that influence the assimilation of SIS.

The characteristics of a data centre's infrastructure influence the decision of choosing the appropriate system required to support that infrastructure. In particular, the type of equipment or system used, the

method used in operating equipment or system, and the special requirement to manage the operations of that equipment or system influence the volume, diversity and intensity of SIS. The type of equipment or system refers to the unique characteristic of an equipment or system that operates in the facility, cooling, power and computing resources management areas. The method refers to the techniques used to configure the systems of the four main data centre areas. The special management requirement refers to the set of functions required to administer and manage the operations of equipments or system and method used.

In most cases, the method used in operating a system influences the volume, whereas the management requirement of a system influences both volume and intensity. For instance, cases one and four use only the water-based CRAC cooling system with room-based cooling and raised-floor method. Most CRAC units are set with one sensor that read the temperature of the entire room and therefore only one sensor is used per room in the two data centres. The CRAC units were designed to operate automatically based on the reading from the one sensor, and thus the special management requirement was limited to monitoring, reporting and alerting the behaviour of the system with only some minor control function. Although both case four and one have adopted raised-floor method, case four did not use underfloor airflow sensors like case one. Case five uses water-chillers plant and free air cooling systems coupled with direct cooling to the "pods". Water-chillers systems require different sets of sensors types such as water-flow, water pressure, and water leakage sensors. Free air cooling requires another set of sensor types such as outside temperature, humidity, airflow, and odour. Direct cooling via pods requires the diffusions of large amount of sensors at each rack to ensure the effective cooling delivery. These systems have special management requirements with high intensity of SIS functions use. Thus case five uses four SIS to effectively handle the operations of the infrastructure. This suggests that the more the data centre is to have an infrastructure that needs higher observation and control, the higher the level of SIS assimilation.

In respect to the age of data centre, case five, which has a newly built facility, has a well-integrated SIS platform whilst recorded the highest level of SIS volume, diversity and intensity. The other cases have yet to integrate SIS. This is partly because their infrastructure is either an old platform (which has retrofit limitations) or is comprised of diverse equipment and applications from different manufacturers (which are not fully compatible). This suggests that newly constructed data centres have a higher capability for SIS integration and, hence, a better level of SIS utilisation.

In terms of business scope, data centres can be classified into four types: corporate data centres, co-location data centres, fully-managed data centres and multi-purposed data centres. Corporate data centres are usually large data centres owned by an organisation for the purpose of supplying computation and information functions specifically to that organisation. In co-location data centres, organisations (clients) rent a space in a shared data centre facility owned by another organisation and bring in their own IT equipment into the facility. In fully-managed data centres, organisations (clients) outsource their entire IT resources and host their IT requirements in servers and a facility that is fully owned by another organisation. Multipurpose data centres provide more than one service of the above three categories. For instance, a multi-purpose data centre could be co-location and fully-managed at the same time. The type of data centre influences the level of SIS use and the application scope of the SIS. For instance, in co-location data centres, the data centre is mainly responsible for, managing the cooling chillers, HVAC systems, power generation, network links and physical security. Thus, the integration of the CSSP and the ICTP is neither necessary nor easily manageable. Furthermore, in co-location data centres, the application scope becomes narrowed with the exclusion of computing infrastructure. Based on the above findings, the following can be proposed,

Proposition 4: While the data centre infrastructure requirements influence the volume, diversity and intensity of SIS, the age and the type of data centres control the extent of SIS assimilation.

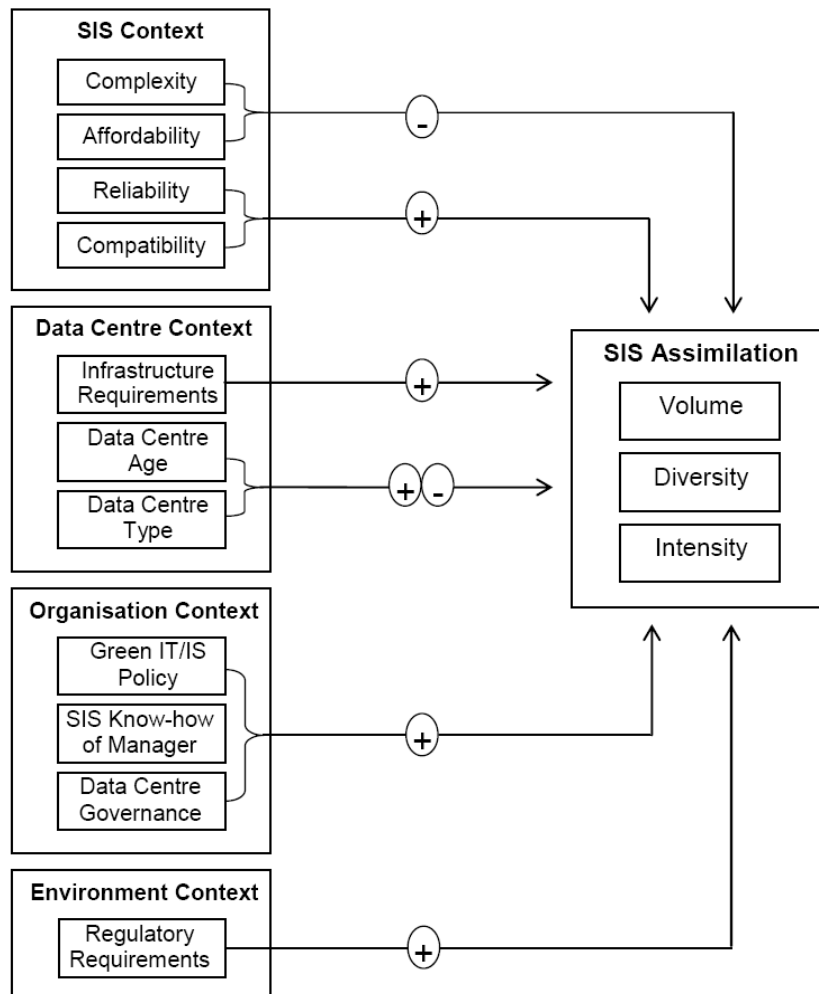Based on the findings above, Figure 2 presents a theoretical model of SIS assimilation in data centres..

Figure 2. *A theoretical model of SIS assimilation in data centres.*

5.   Conclusions

The literature depicts various advantages of applying and utilising SIS in data centres. The result shows that Data Centres can leverage SIS capabilities to improve not only their operational and economic performance but also to improve their environmental footprint. The findings show that there is a significant variation in the assimilation of SIS. The study provides one of the first studies in the use of IS within the data centre environment and the factors that might influence use. It provides one of the first studies in the IS research that attempt to model the SIS use. The study show the utility of Massetti and Zmud's (1996) facets of assimilation for studying the application of IS that have both economical and environmental implications. The results highlight some of the technological, data centre, organisational and environmental reasons that might facilitate or inhibit data centres from using SIS. The proposed model of SIS assimilation redefined some of the TOE variables within the context of Data Centres and also identified new relevant variables for Data Centres. This shows that although the TOE is a relevant conceptual framework to study the antecedent factors that explain the assimilation of SIS in Data Centres, it needs further extension and respecification to cover the context of assimilation such as data centres and emerging issues such as environmental sustainability. The growing importance of environmental sustainability implies that the use or misuse of technology might be influenced by environmental considerations.

The SIS functionalities within a Data Centre platform can be classified into the ICTP functionalities (servers, network and storage) and CSSP functionalities (site, cooling and power management).

Traditionally, data centres have been using sensors for thermal and air-flow management. However, the full realisation of SIS functionalities requires SIS use beyond this limited scope. This involves overcoming the inhibiting factors (such as infrastructure compatibility, complexity) and developing the facilitating factors that are identified in this study. Further the case based framework developed in this study can be used to guide future research in SIS and Green IS.

In conclusion, from both the literature review and case study, the following observations can be made. First, there is a general lack of academic research in the area of data centres and in the assimilation of SIS in data centres specifically. This paper calls for more academic research into the area. Second, most of the existing research focuses on testing SIS designs in an experimental or simulated environment. Therefore, more empirical research is required to understand the real factors that could influence the assimilation SIS in real data settings. Third, integration between CSSP and ICTP systems are the key factor in determining the value of SIS utilisation, and hence successful SIS assimilation in data centres. Integration between different platforms entails some requirements that need to be set properly. It could involve technical issues such as communication standards and protocols, data handling and exchange protocols, hardware and software interoperability, and system security and reliability. Therefore, more theoretical and empirical research is required to investigate the implications of integrating different data centres' platforms.

This study has some limitations. First, the empirical investigation focused only on data centres within Australia. In addition the number of cases is relatively small. Thus the findings can only be considered as a preliminary and require a more in depth study before any conclusion can be made.

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