Critical success factors in implementing flexible IT infrastructure in the Malaysian construction industry

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Abstract

Improved IT products and services are continually being introduced around the world. However, although an increasingly common approach in many industries, little is known of the characteristics of flexible IT infrastructure associated with its successful construction industry implementation. To rectify this situation, this study aimed to identify the critical success factors (CSFs) involved in the delivery of Information Technology Infrastructure Flexibility (ITIF) to the construction industry. An initial list of 38 potential factors divided into technical, people, and management dimensions and associated elements were identified by literature review and preliminary interviews with seven Malaysian companies representing a variety of construction industry participants and IT experts. This was followed by a main study comprising a questionnaire survey of 211 construction industry practitioners in Malaysia. Eighteen critical factors contributing to successful ITIF delivery are identified. Of these, two CSFs of hybrid skill and willingness to change appear to be unique to the Malaysian construction industry. Further research is recommended to assess the opinions of a wider variety of experienced practitioners to validate the findings and its applicability in the Malaysian context and beyond.

KEYWORDS: Information technology, Construction industry, Flexibility, Management, Infrastructure

Introduction

The extremely information-intensive and knowledge-based nature of the construction industry has resulted in information technology (IT) being a driver for many construction business and operational processes (Underwood and Khosrowshahi 2012). This central role of IT has demanded a significant level of investment in IT infrastructure (physical IT assets and software) (Akintoye et al. 2012) and comprising 70% to 80% of most organizations' ICT budgets (Gartner Research 2018; Gray 2009). Despite this large investment in IT infrastructure, many IT failures are still being reported, including construction industry failures (Standish Group 2009, KPMG IT Advisory, 2010). One of the main reasons is due to the pace of current IT innovation having quickened considerably, with dire consequences for ill-considered and ill-timed IT management decisions (Hinssen 2011). The construction industry is therefore affected by this revolution, which is demanding continual upgrading of IT infrastructure (KPMG 2010; Rivard 2000). Furthermore, the IT infrastructure was not designed to support new functions brought about by rapid technological change (NetApp 2011) due to the continuous demand of a new and modern environment (NetApp, 2020). This is especially case in the construction industry, where IT is only a minor aspect of investment, and the integration of current solutions with such future applications as mobile apps, robotics, augmented and virtual reality remains poor among construction players (Yap, Chow and Shavarebi, 2019) as this requires new infrastructure, new skills, and a new management direction (Irfan and Putra, 2019). As a result, IT systems

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are faced with long-term limitations, aggravation and costs, which have become a major burden for construction-related organizations, including carrying out their pre-construction, execution and post-construction roles (KPMG, 2019). IT managers in construction organizations now need to be able to anticipate and quickly react to changes (KPMG IT Advisory 2010).

One approach to ameliorating the effects of this combination of change and burgeoning investment demands is to develop a more adaptive response to changing needs (Jafari et al. 2006; Salman 2009; Yusuf et al. 2011). In this situation, a flexible IT infrastructure is seen to be the key to keeping pace with ever-expanding and changing technologies and to support increased demands for 'anytime and anywhere' access (White 2012, March 11). This flexibility involves accommodating the incorporation or removal of components without the need to be completely redesigned. It also needs to allow customized solutions to meet demand without jeopardizing operations.

Due to the advancements in Building Information Modelling (BIM), the industry is stressing the technical aspects of IT implementation (Latiffi, et.al, 2013). Since then, the industry has realized its dire need for an appropriate and adequate framework to develop a flexible IT infrastructure (CIDB Malaysia, 2011) to respond to the rapidity of technology change and the unique culture and fragmented nature of the industry. A multi-dimensional analysis is needed of the construction industry perspective to deepen understanding of the factors likely to contribute to the success of the implementation of IT infrastructure flexibility (ITIF) in terms of

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technology, people and management. Considering the importance of IT infrastructure in the operations and competitiveness of companies in global markets, these findings can help construction and IT project managers, leaders and organizations in the improvement of project success rates across various projects, departments and organizations.

The originality of this study lies in its purpose to identify the critical success factors (CSFs) involved in the Malaysian construction industry, which will complement existing research ITIF frameworks and function as a guide to develop a more flexible IT infrastructure, including BIM. Malaysia's construction industry, in particular, was introduced to a need for flexible IT infrastructure by the Government in 2011 (Ministry of Works Malaysia 2011). Malaysia has the highest ICT Competitiveness Index of developing Asean countries, with 77% of government services already available online (Tajuddin and Rohman, 2017), which makes for Malaysia a good case for understanding successful IT adoption. Thus, it will be useful in furthering the optimization of flexible IT infrastructure by improving resource utilization, faster provisioning, and better business and cost transparency. It could be also used as a benchmark in other developing countries and as a lesson learnt for the developed countries, especially those that invest in developing countries.

This study, therefore, aims to identify the critical success factors (CSFs) involved in the Malaysian construction industry. In doing this, an initial list of 38 potential factors divided into technical, people and management dimensions, and associated elements were identified by literature review and preliminary study with seven Malaysian companies representing a variety of construction industry participants and IT experts. This was followed by a main study comprising a questionnaire survey of 211 construction industry practitioners, including developers, contractor organizations, architect organizations, surveyor organizations, engineer organizations and construction manufacturers in Malaysia. Details of this and the main findings are provided in the following sections.

Literature review

IT Infrastructure

IT infrastructure is defined broadly by Laan (2017) as the composite hardware, software, network resources and services – such as consulting, education and training – that are shared across the entire gamut of construction organizations. It consists of a technical physical base and a human component, which combine to create the IT services.

In construction organizations, there are two distinct tiers of IT infrastructure within each sub-system. The first delivers specific management functions throughout the corporate organization, while the second will deliver specific functions at the construction project level that are established for each project site (Griffith, Stephenson and Watson, 2014). Both tiers must be interactive and compatible, as each is mutually supportable and must link in and support the core business

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system. The sub-systems should have an ability to share information across the boundaries with other sub-systems. It is the foundation for all kinds of information resources for present and future business applications.

The IT infrastructure must conform with functional and non-functional requirements. Functional requirements describe how the system works, while non-functional requirements describe the how the system works. The acceptance of a system is largely dependent on the implemented of non-functional requirements, but they are always not clearly defined (Laan, 2017). Therefore, if the IT infrastructure is not designed to be flexible, the applications built upon it cannot introduce scalability, reliability, stability, testability, and recoverability as afterthoughts.

IT infrastructure flexibility (ITIF) and its relevance to construction companies

Rigid IT infrastructure is heavily customized at the beginning, the idea being that, in the long run, there will be no need to make changes. In contrast, a flexible IT infrastructure provides the capability of adjusting to a wide variety of IT applications, and has the depth and scalability to meet most construction organizations' needs. It can be diffused into the overall technology platform and distribute any type of information to anywhere inside and outside an organization (Hou, 2019). It becomes flexible when the resources are sharable and reusable. Flexible IT infrastructure also means being easily configurable and adjustable (Hwang, et al., 2011). ITIF enables IT systems to support change and it can be improved without having to start all over again (Butler Group 2006). ITIF implies building a system with the capability of anticipating such distinct requirements as a broad range of products that are suitable for the parties involved (clients, contractors, design team, etc.).

Previous studies by Tallon and Kraemer (2003) showed that ITIF is a key to success for IT during periods of intense change, particularly where flexibility in IT infrastructure acts as a foundation for overall IT flexibility. Generally, flexible IT infrastructure helps construction organizations in handling IT change, caused by a continuous change in the external and internal environment, with minimal increased cost. IT investment is not solely concerned with the product, but also needs longer-term investment for its maintenance, upgrading, and staff training and skills. As technology changes very quickly, construction organizations need to allocate additional investment - the main reason why construction organizations avoid new IT investments. To help overcome this problem, ITIF supports construction organizations by reusing the existing component of IT infrastructure every time new technology is introduced or changes to the IT system are needed. In addition, staff needs additional training to gain new skills and knowledge when there is a change in the IT system, with the cost involved depending on how widespread the system is for the users. With familiar system interfaces, the retraining costs associated with learning and administering the new system, network, and database are reduced; it requires less amount of IT personnel involvement to attend courses, shortens training time for internal

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personnel, diminishes the documentation of procedures and processes, and allows on-the-job training in house. Therefore, by implementing ITIF, construction organizations can obtain cost savings in providing training to their own staff or clients by means of a consistent and unified IT system management (Afuah and Werner 2007).

ITIF allows construction organizations to make the best decision on business-IT infrastructure alignment so that they can quickly adapt to environmental change and explore new ideas for processes (Leana and Barry 2000). As a result, ITIF can shorten product time cycle, increase design alternatives and produce higher quality products (Omar, et al., 2010).

Critical success factors in implementing IT infrastructure flexibility (ITIF) in the construction company

ITIF has been defined by Duncan (1995) as an aggregation of technology components. Based on her work, Broadbent et al. (1996) introduced the concept of ITIF containing various conceptual elements, which include communications management, standard management, application and data management, and human resources management. A few years later, Byrd and Turner (2000) published an exploratory analysis of ITIF constructs, identifying two new categories of skills (technical and IT management skills) and knowledge (self-management and business knowledge). From this, they conceptualized ITIF as a combination of two dimensions - technology and people - with the latter being composed of their skills and knowledge categories. This seminal work has been referred since by many researchers of ITIF, such as Chung et al. (2003), Tallon and Kraemer (2004), and Masrek and Jusoff (2009). Further work by Ozer (2002) and Paschke and Martin (2008) extended these views to include a business process dimension, comprising resource planning and management factors affecting the capabilities of IT and established the significant contribution of the management of ITIF in the effectiveness of IT. Table 1 shows the ITIF dimensions from the previous studies, none of which have been studied in the construction industry. Therefore, ITIF in the construction industry remains poorly understood and there is a need to extend its assessment to construction organizations. This is certainly important, as it would further deepen the understanding of the factors that contribute towards the success of ITIF in the construction industry, considering that construction has unique features that distinguish it from other industries.

Table 1: ITIF dimensions from the research literature.

Fink's work (2009) made a major contribution to developing a valid and reliable instrument to measure ITIF by a rigorous multi-dimensional analysis of ITIF factors that consolidated these previous results into three dimensions termed technical, people and management where the:

- Technical dimension consists of four elements of connection ability, compatibility, modularity and data transparency. It refers to the element of

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IT infrastructure and technical aspect of a particular software development that describes the technologies, which include devices, programming, databases, networking, security and architecture;

- People dimension comprises four elements of technical skill, IT management skill, business functional skill and project management skill. It refers to competencies of IT personnel who involve in development and management of software;
- Management dimension is divided into two aspects of technical-oriented and management-oriented. This dimension refers to the long-term attributes that involved in the supporting the software development.

Fink's factor reliability coefficients were 0.60 to 0.73 for the technical dimension, 0.83 to 0.92 for the people dimension and 0.87 to 0.90 for the management dimension, providing further support for Byrd and Turner's (2000) findings and demonstrating the conformity of these factors for further analysis. Fink's factors were therefore used to measure each element in the current study. The 33 factors involved are summarized in Table 2 and described in more detail below.

Table 2: Success factors of IT Infrastructure Flexibility according to Fink (2009)

The technical dimension

Connection ability refers to the ability of the IT infrastructure to make a connection between two or more points in a network. For IT infrastructure to be flexible, it should allow all networks to connect across large platforms (Greenberg et al. 2009). Four factors are identified as measures of connection ability IT system utilization, 24-hour connection, a VLAN, and minimal steps for data access.

Compatibility measures the ability of the IT infrastructure to share information within or/and across IT systems. To utilize BIM, for an example, it is necessary to ensure any new IT system supports interoperability between digital files so that they are readable by BIM software. Therefore, it is significance to measure how construction organizations ensure the system's compatibility through the standardization of file formats, especially in engaging facilities management (FM) in design stage through BIM (Wang, et.al, 2013) when there are many systems involved in integrating a BIM model with a facility's maintenance management system. The four factors measured for compatibility are common operating system, standardization of file formats, quick integration, and transparent access.

Modularity involves creating the most efficient modular IT architecture to support existing and new IT products, which measures the ability of IT infrastructure to be easily configured and reconfigured. The important factor of this element occurs during the design stage prior to its development. The purpose of the system design is to create a technical solution that satisfies the functional requirements of the system while considering its long-term adaptability (Pataki et al. 2003). Modularity is measured by three factors, namely reconfigurable system design, reusable applications used, and utilization of OOP technologies.

Byrd and Turner (2001) define data transparency as the ability of IT infrastructure to easily access and work with data no matter where the data are located, with an assurance that the data being reported are accurate and from official sources. Data transparency determines the effectiveness of the system data analysis. An analytical processing tool enables multidimensional data analysis from multiple perspectives (Perkova 2011).

The people dimension

Byrd et al. (2004) found that IT personnel need to possess hardware and software IT skills to gain confidence in dealing with the changing demands of IT infrastructure. They must be skilled in multiple operating systems (OS), multiple programming languages, network management and maintenance, and in data warehousing. This will enable them to manipulate the hardware and software more easily. The IT personnel need also to be cross-trained to support other IT services outside their primary knowledge domain.

IT management skill under the people dimension refers to qualities or competencies needed for IT personnel to succeed. The first factor for this element is 'be updated', which concerns IT personnel awareness of updates and the latest events in the IT field, along with technical reviews and news (Rong and Grover 2009). In addition to IT awareness, personnel commitment is assessed in the context of the dedication of IT personnel to learning about the latest tools, applications, systems, processes, etc., involved.

Teamwork proficiency is defined by Palit and Stein (2009) as a 'collaboration skill' involving the ability to work in groups with persons of different background, think critically in solving problems and to communicate effectively, both orally and in writing. Good teamwork is important in facing challenges that occur during the development of IT infrastructure – teams carry out many critical functions, including information collection and dissemination, decision-making and implementation, where these elements contribute to a successful IT project (Davison and Ward 1999). Self-directed skill is an aptitude to work usual managerial supervision toward a common purpose or goal (Fisher 2000). In other words, an individual who has this skill is able to work effectively independently. Thinking and acting ahead in anticipation of future problems, needs or changes are the qualities brought by IT personnel in being pro-active (Larsen 2010).

The identification of an IT project's CSFs is important for its success; therefore, IT personnel need to possess IT project management skills and especially an ability to determine the CSFs involved (Kandelousi et al. 2011). Understanding their project CSFs allows IT personnel to predict risk and hence save cost and shorten the project timeframe (Dobbis 2001). It is also allows members of the team to work

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towards similar goals and assess and adjust the organization's direction in response to a changing environment (Gates 2010).

The management dimension

Under the technical-orientation, connectivity is the capacity for the interoperability of platforms, systems and applications (Youngs, 2013). Connectivity resources of can assessed through various discrete networks. To boost connectivity, communication channel management administers use different communication platforms - intranet and external websites for example. IT security management (confidentiality, integrity and availability of information) safeguards the accuracy and completeness of information, making it accessible only to authorized users when required (Jaferian et al. 2008). This is important to protect valuable information from threats inside and outside the organization. Data management is the day-to-day process of managing data as a valuable resource to an organization and involves data architectures, practices, and procedures related to data (Gray et al. 2005).

The management-orientation involves few factors. Standard operating procedures (SOP) comprise a set of written instructions that document a routine activity that provide individuals with the information needed to perform a job properly (Ashworth, et.al, 2019; Loosemore and Teo 2012). Project management is very important in ensuring projects are run efficiently and successfully delivered

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according to the clients' expectations and within an agreed timeframe and cost (Lacerda et al. 2011). Continuous training and education at all levels is necessary for staff to be familiar with latest technological developments (Akintoye et al. 2000; Edum-Fotwe and McCaffer 2000). In addition, research and development is important in the construction industry to successfully address its IT challenges and remain competitive (Kalatunga et al. 2011).

Methods

Preliminary study

Due to lack of construction industry data in previous research, a preliminary study was conducted to ascertain the extent to which the factors of ITIF gathered from the literature are relevant to construction industry practices. Data collected during the preliminary study focused on the CSFs of ITIF in terms of technical, people and management dimensions and associated elements based on the success and failure experience of each organization. Seven construction companies were selected to participate in the preliminary study. The selected companies were from different areas of the construction industry - a policy maker, construction consultancy practice, contractor, materials supplier, IT developer, and an IT consultant company with ten-year experience in developing IT systems for the Malaysian construction industry. All the selected companies have an IT department. The participant mixture provided a diverse set of views and perspectives from the various professionals involved in the industry. These included the Chief Information Officer, Head of the IT Department, and IT Manager and Software Engineer, of which at least two represent each construction of the companies involved. Semi-structured interview sessions were carried out to allow them to give their opinions and views on the relevancy of ITIF success factors to the construction industry. The participants were also given the opportunity to propose other factors that contribute to flexibility in IT infrastructure. The data collected focuses on the success factors of ITIF based on each organization's experiences of success and failure.

The 33-factor framework identified from the general literature review was presented to the interviewees for comment and adjustment. Except for some minor changes in terms of terminology, the framework and its constituent factors was accepted as being a reasonable representation of the main issues involved in providing ITIF in the Malaysian construction industry. In addition, a further five factors were identified based on the consistency of agreement between the participants, (where at least 70% of the total number of participants were in the agreement) comprising:

- The utilization of virtual private networks (VPN);
- Willingness of change;
- An ability to interpret management and technical needs;
- Familiarity with environmental constraints within the construction industry;
- An understanding of construction processes and stages

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Virtual private networks (VPN) allow remote access to enterprise data and is therefore one of the technical dimension's connectivity elements. ‘Willingness of change’ enables IT personnel to easily adapt to working effectively in various situations and with other individuals and/or groups. This also involves the understanding and appreciation of diverse and opposing perspectives on an issue, adapting one’s approach to the changes at hand, and easily accepting and making such changes, whether in one’s own duties or in the organization's strategic direction (Napshin and DeCarolis 2011). An ability to interpret management and technical needs helps IT personnel to appreciate management requirements before proposing a technical solution for any particular project (Noe, et.al, 2017). It allows IT personnel to predict risk and hence saving cost and shortening the project timeframe.

The other two factors are business knowledge elements. These concern the IT personnel’s knowledge of the construction industry. In many businesses, including the construction industry, IT personnel are typically from one of two types of background (Bourgeois, 2014). The first concerns IT professionals, which include Chief Information Officers (CIO), Heads of IT Department, IT Directors, IT Managers and IT professionals such as programmers and system analysts. This group of IT personnel is usually involved in the technical decisions of IT projects and should be familiar with the construction industry dealing with economic, legal, environmental, technical and social constraints. Therefore, it is essential to develop IT by including these constraints in design considerations. The second comprises non-IT professionals with experience as leaders in the planning and IT decision-making in their organizations - architects, engineers, project managers and surveyors for example. IT personnel should be able to understand the common processes involved in construction, such as the procurement process, tendering process, payment process and the process of building a project. Both these factors require a broader knowledge of IT personnel in the construction industry, where they differ in their awareness of CSF, as this factor focuses on construction organizational issues. The managerial perspective helps in this study to acquire an insight into key business areas in advancing the organization's goals through the perspective of technology, people and management issues, thus benefitting managers in understanding the market and competition in IT implementation. This extended framework of 38 factors is summarized in Table 3.

Table 3: **Success factors of IT Infrastructure Flexibility*Main study***

Data collection

In the next stage of the research, a questionnaire survey adapted from Byrd and Turner (2001) and Fink (2009), was conducted in order to identify the most important perceived success factors in ITIF implementation from a construction industry perspective. Respondents were informed of the meaning of ITIF and asked to rate 38 items on a bi-polar 5-point Likert scale, ranging from "1-strongly disagree" to "5-strongly agree". Before the questionnaire was sent out, a content validation process was carried out through discussions with several IT practitioners

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in the construction industry and an IT academician. These comprised three IT managers and two senior IT technicians from construction companies that have been established more than ten years, a Director from a public-listed development company on the main board of the Kuala Lumpur Stock Exchange (KLSE) and an academician with more than ten years of experience researching construction IT in the United Kingdom. The interviewees were firstly briefed on the purpose of the study, and then asked to evaluate the questionnaire items for their understandability, clarity, relevance and completeness.

Potential questionnaire respondent organizations were selected from various databases, based on the categorizations listed in the Construction Industry Development Board of Malaysia’s website, in order to ensure a diversity of views of ITIF success factors. These potential respondent organizations included developers, contractor organizations, architect organizations, surveyor organizations, engineer organizations and construction manufacturers in Malaysia. Given that most of the measures require IT familiarity and understanding, this study sampled the respondents from a population of construction organizations actively using IT in their business. Selection was based on the availability of IT departments in the respective organizations through confirmation by telephone or electronic mail. The individual respondents themselves include General Managers, IT Directors, IT Managers, IT professionals and construction professionals holding IT-related management-level positions. A summary of the research key aspects were explained to obtain the respondents' agreement to take part in the research, that they were fully aware of the nature of the research and their required role.

Questionnaire returns were accepted for approximately fourteen weeks since the first distribution. The survey was finalized when no questionnaires were returned for more than a week, after several efforts were made in terms of personal contacts and follow-up calls.

Analysis

The perceived importance of the ITIF success factors are measured through a 5-point Likert scale with graded item responses ranging from "1 – Not Relevant at All" to "5 – Strongly Relevant", hence the factors are treated as ordinal variables (Hennig et al. 2003). The relevant non-parametric tests are used in the form of mean, Severity Index and Kendall's W tests for data ranking, and supported by Spearman's Rho correlation coefficient. A combination of these tests has been widely used by many researchers previously in the process of identifying CSFs (Fan et al. 2012; Ganesh and Mehta 2011; Idrus and Newman 2002).

The analysis begins with data ranking. The 'mean score' method was used to analyze the questionnaire findings to establish the relative importance and relevance of the respondents' opinions respectively. Having observed the most likely important ITIF success factors based on frequencies, a test of severity is carried out to establish its validity. The purpose of this is to select the CSFs of ITIF for the development of a maturity model. The severity index (*SI*) is measured using the Yusuf et al. (2011), formula where

$$SI = \left(\frac{\sum WF}{n} \right) 100\% \quad (1)$$

W is the weight for each rating (being equal to proportional rating to the number of points in the scale, in this case 1/5, 2/5, 3/5, 4/5, and 5/5), *F* is the frequency of responses for each scale, and *n* is the total number of responses (in this case *n*=211). The Severity Index is used to identify the CSFs by determining the relative important index for each variable, which is then used to rank the variables according to their degree of importance (Ogwueleka 2011; Oyewobi and Ogunsemi 2010; Yusuf et al. 2011).

Kendall's W test is applied to compare the ranking of the variables to ensure that the ranking of the variables obtained from the Severity Index is a result of a consensus agreement between the different groups of respondents (Ganesh and Mehta 2011; Idrus and Newman 2002; Ifinedo 2011).

The top-ranked variables that meet the criteria set for mean, Severity Index, and Kendall's W mean rank results, are shortlisted. The significance of the correlation of the shortlisted variables was tested using the Spearman's rho (ρ) correlation coefficient where

$$\rho = 1 - \frac{6\sum d_i^2}{n(n^2 - 1)} \quad (2)$$

with $\sum d^2$ being the sum of the squared differences between the pairs of ranks and n the number of pairs (Field, 2013). Using a standard table of probabilities, p, for ρ, the usual criterion is adopted in that $p<0.05$ denotes a significant correlation of the respondents' rating of the ITIF success factors. As with previous studies, these significantly correlated variables are taken to support the existence of a causal relationship among the factors for successful implementation of ITIF and hence as contributory CSFs (Fan et al. 2012).

Analysis and results

Altogether, although the response rate is only 21.1%, representing 211 respondents out of 1000 questionnaires sent out across all over Malaysia, it is consistent with the normal response rate of around 20 to 30 percent for postal questionnaires in the construction industry (Akintoye 2000; Takim and Adnan 2008; Yang et al. 2011). Takim and Adnan (2008) and Adnan and Morledge (2003), for example, received a 20.9% and 20% response respectively in their surveys.

All the respondents work for construction business sectors, the majority being from the building sector, and all hold IT-related management-level positions, with over half (57%) being IT Managers/Heads of IT Department and a further 25% comprising construction professionals. This is beneficial as a managerial perspective is important to provide valid evaluations of strategic measures, as is the IT respondents' technological background and IT familiarity/understanding. Over half (53%) the respondents are also very experienced, with more than 10 years working experience in construction IT departments, while only 10% have less than 3 years working experience. The organizational profile of the companies involved, with 66% employing less than 200 people and 63% having an annual turnover of less than RM100 million (USD23.4 million), matches the industry as a whole. This coverage, therefore, provides both a good level of knowledge and expertise of IT issues as well as a reasonable cross section of people and professions in the Malaysian construction industry.

Cronbach's α coefficients for the item scores for the technical, people and management's dimensions are 0.867, 0.867, and 0.849 - indicating, with $\alpha > 0.70$, that the ITIF success factors have a significantly high internal consistency (Morgan et al. 2011).

Tables 4, 5 and 6 show the results of the ranking tests for the three dimensions and from which the most generally favorable ITIF success factors are short-listed. The variables are selected based on the consistent ranking made by statistical tests. Severity indices for selected variables (for all dimensions) are more than 70% with means above 3.50. This indicates that respondents perceive these variables to be highly critical and influential in ITIF implementation, as higher ranked variables can be considered to provide a greater contribution to ITIF (Oyewobi and Ogunsemi 2010). In support of the high ranking of the variables through the means and severity indices, Kendall's W mean ranking values indicating that the variables also have a high consensus consistency and hence a high proportion of respondents agree with this perception.

Table 4: Ranking of success factors of flexible IT infrastructure for the *technical dimension*

Table 5: Ranking of success factors of flexible IT infrastructure for the *people dimension*

Table 6: Ranking of success factors of flexible IT infrastructure for the *management dimension*

Table 4 provides the ranking results for the technical dimension, with the variables within this dimension having an overall mean in the range of 3.11 to 3.76. Six ITIF factors, namely TCon1, TDat4, TCom1, TCom2, TCom3 and TMod1, consistently rank in the highest indicators. Their severity indices ranging from 70.90% to 77.17%, with Kendall's W mean ranging from 20.00 to 23.52.

The variables in the people dimension have means ranging from 3.01 to 4.05, with Kendall's W mean values between 14.45 and 24.78 (Table 5). Eight variables are ranked in the highest position under the people dimension, namely PTech5, PMngt1, PMngt2, PMngt3, PMngt4, PPer1, PPer2 and PCknow1, with severity indices from 70.62% to 86.16%. The variable PMngt1 is the highest in the overall ranking.

For the management dimension, the variables' means range from 3.16 to 3.85, with severity indices from 63.22% to 76.97%, and Kendall's W mean from 15.01 to

22.41. Table 6 shows the consistency in ranking of all the variables in this dimension. The top four variables in this dimension are MSup3, MSup2, MSup4 and MSup6.

The other twenty variables have a severity index of less than 70%, with means lower than 3.50 and Kendall's W mean ranking below 19, indicating their relatively lower level of influence on successful ITIF implementation.

Table 7: Spearman's rho correlation matrix

Table 7 presents Spearman's rho correlations between the ranked variables, indicating the majority to be significantly positively correlated, $\rho > 0.200$, p (two-tailed)<0.05. Of the total 18 variables, 14 (TCom2, TCom3, TMod1, PMngt1, PMngt2, PMngt3, PMngt4, PPer1, PPer2, PCKnow1, MSup2, MSup3, MSup4, and MSup6) are significantly correlated with at least 5 other variables, which strongly suggests a genuine relationship between them. The scatterplots for a few samples of CSFs are shown in Figure 1, indicating the positive associations within and between the different dimensions. These show the best fit of a straight or linear regression line, where the points fit the line quite closely; $r^2 > 0.200$. Less certain are the four remaining variables, which for robustness purposes may be eliminated from consideration for short listing at this stage.

Figure 1. Correlation samples

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Discussion

The technical dimension lists three critical factors of ITIF. For the construction industry, it is a challenge to standardize the file formats because there are different kinds of formats for different kinds of information. Therefore, it is important to measure how construction organizations ensure the system's compatibility through the standardization of file formats. A faster integration speed indicates a more compatible system (Xu and Liu 2011). Modularity involves creating the most efficient modular IT architecture to support existing and new IT products, which measures the ability of IT infrastructure to be easily configured and reconfigured, by considering long-term adaptability system (Pataki et al. 2003). The technical dimension element of data transparency is scored the lowest rank in the technical dimension. The main reason for this is the opacity of the data obtained from raw materials, making it difficult to assess its original source (Nordin 2012). It thought that this limitation is purposely created in the Malaysian construction industry to make manipulation virtually undetectable (Wan-Abdullah et al. 2012). Consequently, it is difficult to provide data transparency in an IT infrastructure system.

Seven factors are critically listed under the people dimension, comprising: teamwork and self-directedness, pro-activeness, be updated, commitment to learning new IT processes, willingness to change and hybrid skill, as well as project management skill. An interesting result arising from this analysis is the emergence of two new success factors for the application of ITIF in the Malaysian construction industry - (1) hybrid skill and (2) willingness of change. The skill of interpreting technical and management needs is important for IT personnel in understanding business objectives (Willcocks et al. 2012). Both set of skills help IT personnel appreciate management requirements before proposing a technical solution (Noe, et.al, 2017). This finding has become a global issue (Mantelaers and Berg 2000) and reflects that construction literacy among IT personnel working in the industry is equally important and needs to be emphasized to ensure IT achieves its goals in term of construction solutions and IT effectiveness. Willingness to change is a behavior that has become one of the core competencies of adaptive IT personnel (Stefanovic et al. 2011), enabling an easy adaption to working effectively with other individuals and/or groups in a variety of situations; understanding and appreciating diverse and opposing perspectives on issues; adapting one's approach to the changes at hand, and easily accepting and making such changes, whether in the pursuance of one's own duties or in following organizational strategic directions (Napshin and DeCarolis 2011). Both of these factors are significant in determining the success or otherwise of the application of IT infrastructure flexibility in the long term. This is an indicator that the culture of change in developing countries is still in its infancy and thus it calls for international construction investors to address this issue when doing business in such regions.

The lowest ranked are all the technical skill measures of the people dimension. IT personnel are required to be IT-literate, with advanced skills usually being

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obtained through continuous learning such as provided by attendance at short advanced courses and seminars (Hashim 2007). Standard operating procedures are less used in the Malaysia context, as *ad hoc* approaches are more commonly used during events when changes occur (Zamli et al. 2007). In the management context, *ad hoc* decision-making is task-oriented problem solving, made only when needed for a specific purpose and without planning or preparation (Macmillan Dictionary 2011). This is typical of the construction industry as a whole for, as reported by Stanford University (1995), construction organizations respond to conditions as they arise, often in an *ad hoc* fashion and do whatever is necessary to implement change. As Howes (2000) also emphasizes, the implementation of IT in the construction industry has happened in an unplanned fashion and not through conscious reengineering or preceded by extensive research. This suggests that the construction industry generally prefers an *ad hoc* approach to decision making instead of the systematic analysis provided by standard operating procedures, probably due to the flexibility offered and reluctance to adopt implementation guidelines.

The management dimension results rank connectivity, IT security and management, data management and IT project management as the most critical factors. Training, education and R&D have been found in many studies to have a significant positive effect on productivity generally (e.g., Erzil and Zhen (2012)). The research findings, however, provide a contrasting result. Even though these two factors are known to be important components in strengthening an organization's competitive advantage, the Malaysian construction industry holds them in little regard. This is also true of previous recent research, where IT training and education was reported as lacking in the development of IT projects in Malaysia (Meng et al. 2013). The reason may be that, in a context of R&D, Malaysia in general lags far behind countries such as Singapore, Brazil and India, even though national investment in R&D is increasing year-by-year (Cornell University, INSEAD, and WIPO, 2018). The establishment of the Construction Research Institute of Malaysia (CREAM) plays a big role in leading the implementation of R&D in the Malaysian construction industry, and yet spending on R&D is the lowest among other sectors in the country (MASTIC 2008). It is likely that respondents ranked this factor so low because they perceive R&D to be very expensive and the chances of successful implementation quite small, with a low rate of commercially successful ideas in general in Malaysia. As observed earlier by Sew (2007), this may be due to the lack of incentives for, and benefits of, R&D work in the Malaysian construction sector. R&D work may therefore be commissioned in an *ad hoc* manner to deal with production issues - making it infrequent, informal and difficult to capture. This is not only a local issue, however, but has become a challenge faced by developing countries throughout the world (UNESCO 2010). This finding enlightens international construction investors of IT strategic planning regarding the organizational culture of developing countries.

Conclusion

The construction industry is an information-intensive and knowledge-based industry and hence construction organizations increasingly need to exploit IT fully in order to remain competitive. At the same time, improved IT products and services are continually entering the global market, resulting in a constantly burgeoning heavy IT investment load. Flexible IT infrastructure, such as cloud and managed hosting, offers a means of amelioration. However, although an increasingly common approach in many industries, little is known of the characteristics of flexible IT infrastructure associated with successful construction industry implementation.

The study identified a set of CSFs within an overall framework of three technical, people and management dimensions. This confirmed the applicability to the construction industry of several of the factors known to determine the successful application of Information Technology Infrastructure Flexibility (ITIF) in general. Of special interest, however, is the emergence of two new CSFs of *hybrid skill* and *willingness to change* in relation to the Malaysian construction industry as these are important for IT personnel in understanding business objectives and helping appreciate management requirements before proposing a technical solution, and enabling an easy adaption to working effectively with other individuals and/or groups in a variety of situations. The extent to which these are unique to the Malaysian construction industry remains and issue for further research.

This research contributes to knowledge by complementing existing research ITIF frameworks. The participants were both industry practitioners and academicians with a wide range of experience and expertise in the construction industry and IT. The context is different from previous studies, which tested the ITIF factors across industries other than the construction industry. Thus, it complements other ITIF research in contributing to understanding how construction organizations evaluate their IT infrastructure performance by considering the flexibility issue. Additionally, as the use of construction management software and other digital tools form the basis for managing all aspects of a construction process, the findings further provide contextual explanations for the success of IT implementation by construction organizations. Although not completely representative of the insider scenario in the construction industry, the findings draw attention to the success of IT infrastructure issues in a developing country. They thus serve as a sneak-peak into CSF of ITIF that could contribute to successful management.

From a practical point of view, the identification of ITIF critical success factors contributes to the construction industry as a whole in Malaysia, and potentially to the international market too, due to the common characteristics of the construction industry shared globally. In addition to helping practitioners enhance their understanding towards ITIF capability, the findings also assist in establishing a basis for the industry's strategic development in the future. By using ITIF CSFs, the implementation of IT will able to manage the changing technology due to its ability to optimize the functions based on the multi-disciplinary needs by considering a holistic dimension. These findings could also be useful in improving the Malaysia BIM Standard and Guidelines. Future development of IT systems related to BIM should also consider ITIF CSFs so that the system is flexible and will able to cope with continual technology change. This will provide long-term benefits for IT investments by the organizations that adopt BIM, hence delivering construction project success.

As there is no database for construction organizations with IT Departments in Malaysia, the questionnaire was sent to approximately 1000 randomly selected construction organizations without knowing their IT experience, if any, hence resulting in a small but acceptable response rate which were 21.1%. Further studies involving the opinions of a wider variety of experienced practitioners are needed to substantiate the findings and identify the extent to which they are applicable in the Malaysian context and beyond, including analyzing the differences in consensus between each roles involved in the construction industry. Other variables from more recent studies also need to be considered for incorporation in future studies to ensure the findings reflect the current state of advancement of IT at the time.

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Table 1: ITIF dimensions from research literature.

ITIF Dimensions	Researchers	Industries
Technical	Duncan (1995), Tallon& Kraemer (2003), Ness (2005), Turner & Lankford (2005), Jorfi, Nor & Najjar (2011).	▪ Petroleum ▪ Communications ▪ Consulting ▪ Retail ▪ Insurance ▪ IT
Management	Broadbent (1996)	▪ Finance ▪ Retail ▪ Manufacturing
Technical People	Byrd & Turner (2000), Chung et a l (2003), Byrd, Lewis & Turner (2004), Chung et al (2005), Chanapos et al (2006), Fink & Neumann (2007), Jie, Han & Jennifer (2009), Masrek & Jusoff (2009)	▪ Manufacturing ▪ Insurance ▪ Health ▪ Services ▪ Retail ▪ Utilities ▪ Banks & financial ▪ Transportation ▪ IT ▪ Communications ▪ Financial ▪ Government ▪ Real estate ▪ Wholesale
Technical People Management	Paschke & Martin (2008), Fink (2009), Ozer (2002)	▪ IT

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Table 2: Success factors of IT Infrastructure Flexibility according to Fink (2009)

Dimensions	Elements	Factors
Technical	Connection ability	1. IT system utilization 2. 24-hours connection 3. Virtual Local Area Network (VLAN) utilization 4. Minimal steps for data access
	Compatibility	5. Common operating system (OS) 6. File formats standardization 7. Quick integration 8. Transparent access
	Modularity	9. Design to be reconfigurable 10. Reusable applications used 11. Object-oriented programming (OOP) technologies utilization
	Data Transparency	12. Analytical processing utilization 13. Access control level (ACL) utilization 14. Central data processing 15. Real-time information
People	Technical Skill	16. Multiple operating system (OS) skill 17. Multiple programming languages skill 18. Network management and maintenance 19. Data warehousing 20. Cross-trained
	IT Management Skill	21. Commitment to learn 22. Be updated
	Self-Management Knowledge	23. Teamwork in multidisciplinary environment 24. Self-directed and pro-active
	Business Knowledge	25. Awareness of critical success factors (CSF)
Management	Technical-oriented Services	26. Communication channel management 27. IT security management 28. Connectivity 29. Data management
	Management-oriented Services	30. Standard operating procedures (SOP) 31. Project management 32. Training and education 33. Research and development

Table 3: Success factors of IT Infrastructure Flexibility

Dimensions	Elements	Factors
Technical	Connectivity	1. IT system utilization 2. 24-hour connection 3. Virtual Local Area Network (VLAN) utilization 4. Virtual Private Network (VPN) utilization 5. Minimal steps for data access
	Compatibility	6. Common operating system (OS) 7. File format standardization 8. Quick integration 9. Transparent access
	Modularity	10. Design to be reconfigurable 11. Reusable applications used 12. Object-oriented programming (OOP) technologies utilization
	Data Transparency	13. Analytical processing utilization 14. Access control level (ACL) utilization 15. Central data processing 16. Real-time information
People	Technical Skill	17. Multiple operating system (OS) skill 18. Multiple programming languages skill 19. Network management and maintenance 20. Data warehousing 21. Cross-trained
	IT Management Skill	22. Commitment to learn 23. Be updated 24. Willingness to change 25. Ability to interpret management and technical needs
	Self-Management Knowledge	26. Teamwork in multidisciplinary environments 27. Self-directed and pro-active
	Business Knowledge	28. Awareness of critical success factors (CSF) 29. Familiar with the construction environment constraints 30. Understand construction processes
Management	Technical-oriented Services	31. Communication channel management 32. IT security management 33. Connectivity 34. Data management

Table 4: Ranking of success factors of flexible IT infrastructure for the *technical dimension*

Code	Independent Variable	Mean	Kendall Mean		Severity Index		Overall ranking
			Value	Rank	Percentage (%)	Rank	
TMod1	Design to be reconfigurable	3.76	20.71	4	77.17	1	1
TCom2	Standardization of file formats	3.75	21.92	2	75.07	2	2
TCom1	Common OS	3.73	21.74	3	74.69	3	3
TCom3	Quick integration of new system	3.65	20.17	5	73.08	4	4
TDat4	Real-time	3.60	20.00	6	71.94	5	5
TCon1	Utilization of IT communication	3.55	23.52	1	70.90	6	6
TCom4	Transparent access	3.41	17.27	10	68.25	7	7
TDat1	Utilization of analytical processing	3.38	17.09	12	67.68	8	8
TMod3	Utilization of OOP	3.38	17.75	8	67.58	9	9
TMod2	Reusable applications used	3.33	17.31	9	66.54	10	10
TCon5	Minimal step for data access	3.32	16.92	13	66.36	11	11
TDat2	Utilization of ACL	3.27	19.73	7	65.40	12	12
TCon2	24 hours connection	3.20	17.20	11	63.98	13	13
TDat3	Central data processing	3.15	15.73	14	62.94	14	14
TCon4	Utilization of VPN	3.13	15.66	15	62.65	15	15
TCon3	Utilization of VLAN	3.11	15.28	16	62.18	16	16

Table 5: Ranking of success factors of flexible IT infrastructure for the *people dimension*

Code	Independent Variable	Mean	Kendall Mean		Severity Index		Overall ranking
			Value	Rank	Percentage (%)	Rank	
PMngt1	Commitment to learn	4.05	24.00	2	81.04	2	2
PPer2	Self-directed and pro-active	4.02	24.78	1	80.38	3	3
PMngt3	Willing to change	3.93	23.64	3	78.58	4	4
PMngt2	Updated	3.91	23.27	4	86.16	1	1
PMngt4	Able to interpret management & technical needs	3.75	21.86	7	74.98	5	5
PPer1	Teamwork in multidisciplinary environment	3.71	21.95	6	74.22	6	6
PCKnow1	Awareness of CSF	3.56	19.62	9	71.28	7	7
PTech5	Cross-trained	3.53	20.47	8	70.62	8	8
PCKnow3	Construction processes	3.50	18.98	11	69.95	9	9
PTech3	Network management & maintenance	3.47	22.77	5	69.48	10	10
PTech1	Multiple OS skills	3.43	19.06	10	68.53	11	11
PCKnow2	Environment constraints	3.43	18.00	12	68.53	11	12
PTech4	Data warehousing	3.23	16.00	13	55.45	14	14
PTech2	Multiple programming languages skills	3.01	14.45	14	60.28	12	13

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Table 6: Ranking of success factors of flexible IT infrastructure for the *management dimension*

Code	Independent Variable	Mean	Kendall Mean		Severity Index		Overall ranking
			Value	Rank	Percentage (%)	Rank	
MSup3	Connectivity	3.85	22.41	1	76.97	1	1
MSup2	IT security & management	3.78	22.28	2	75.55	2	2
MSup4	Data management	3.73	21.08	3	74.60	3	3
MSup6	IT project management	3.51	19.27	4	70.14	4	4
MSup5	Standards operating procedures	3.49	19.01	5	69.86	5	5
MSup1	Communication channel management	3.48	18.61	6	69.57	6	6
MSup8	Research & development	3.23	16.46	7	64.64	7	7
MSup7	Training & education	3.16	15.01	8	63.22	8	8

Table 7: Spearman's rho correlation matrix

		TCon1	TDat2	TCom1	TCom2	TCom3	TMod1	PTech5	PMngt1	PMngt2	PMngt3	PMngt4	PPer1	PPer2	PCKnow1	MSup2	MSup3	MSup4	MSup6
TCon1	*rho*	--	.143	.219	.416	.245	-.038	.079	.035	.371	.436	.207	.143	.228	.281	.129	.373	.362	.282
	p		.038	.001	.000	.000	.581	.251	.613	.000	.000	.003	.038	.001	.000	.061	.000	.000	.000
TDat2	*rho*	--	--	.104	.240	.214	.209	.299	.212	.111	.099	.273	.351	.033	.278	.339	.207	.325	.142
	p			.131	.000	.002	.002	.000	.002	.108	.150	.000	.000	.630	.000	.000	.002	.000	.039
TCom1	*rho*	--	--	--	.399	.528	.290	.036	.071	.212	.303	.285	.115	.259	.256	.348	.287	.271	.202
	p				.000	.000	.000	.602	.302	.002	.000	.000	.096	.000	.000	.000	.000	.000	.003
TCom2	*rho*	--	--	--	--	.513	.250	.154	.134	.344	.477	.218	.293	.147	.304	.256	.596	.253	.297
	p					.000	.000	.025	.051	.000	.000	.001	.000	.033	.000	.000	.000	.000	.000
TCom3	*rho*	--	--	--	--	--	.245	.160	.143	.271	.481	.344	.290	.327	.497	.257	.356	.311	.249
	p						.000	.020	.038	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
TMod1	*rho*	--	--	--	--	--	--	.106	.331	.206	.159	.166	.233	.203	.258	.379	.149	.267	.328
	p							.124	.000	.003	.021	.016	.001	.003	.000	.000	.031	.000	.000
PTech5	*rho*	--	--	--	--	--	--	--	.286	.349	.204	.267	.342	.268	.323	.232	.008	.137	.446
	p								.000	.000	.003	.000	.000	.000	.000	.001	.914	.047	.000
PMngt1	*rho*	--	--	--	--	--	--	--	--	.315	.333	.419	.582	.342	.371	.316	.239	.290	.251
	p									.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
PMngt2	*rho*	--	--	--	--	--	--	--	--	--	.541	.372	.349	.439	.434	.291	.295	.371	.430
	p										.000	.000	.000	.000	.000	.000	.000	.000	.000
PMngt3	*rho*	--	--	--	--	--	--	--	--	--	--	.518	.401	.580	.500	.392	.525	.488	.525
	p											.000	.000	.000	.000	.000	.000	.000	.000
PMngt4	*rho*	--	--	--	--	--	--	--	--	--	--	--	.675	.404	.547	.451	.381	.310	.354
	p												.000	.000	.000	.000	.000	.000	.000
PPer1	*rho*	--	--	--	--	--	--	--	--	--	--	--	--	.453	.530	.433	.374	.207	.367
	p													.000	.000	.000	.000	.003	.000
PPer2	*rho*	--	--	--	--	--	--	--	--	--	--	--	--	--	.546	.524	.381	.360	.441
	p														.000	.000	.000	.000	.000
PCKnow1	*rho*	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.329	.343	.254	.344
	p															.000	.000	.000	.000
MSup2	*rho*	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.397	.438	.433
	p																.000	.000	.000
MSup3	*rho*	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.462	.227
	p																	.000	.000
MSup4	*rho*	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.332
	p																		.000
MSup6	*rho*	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	p																		

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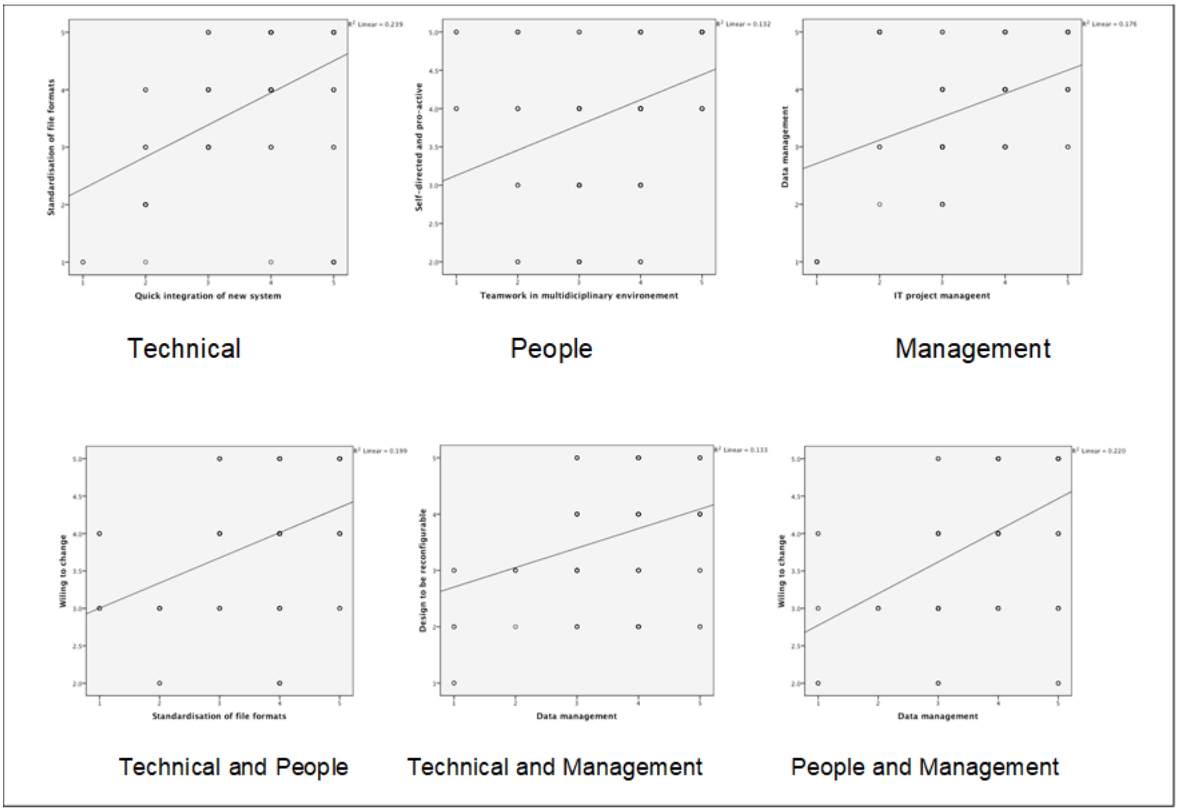
Indicators:

rho	= Spearman's correlation coefficient
p	= Significance
(shaded box)	= H_1 ($p > .05$) – There is no significant correlation among the respondents rating for the ITIF success factors.

Figure 1: Correlation sample



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