Assessing the Impact of Smart Technologies on Project Management: The Case of Singapore

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Abstract
Integrated, digitalized and automated value chains can be recognized as the fundamental characteristics of the Fourth Industrial Revolution and can overcome many challenges faced by industries. To effectively utilize smart technologies in the construction industry, it is essential to understand how these technologies impact project processes. Hence, this study aims to provide a better understanding of the impact of smart technologies on project management knowledge areas to anticipate the changes in project management processes. This study has the following research objectives: (i) investigate the smart technologies with the greatest impact on project management; (ii) assess the specific project management knowledge areas that will be significantly affected by the technologies; and (iii) statistically analyze if organizations of different sizes perceive the impact on project management knowledge areas differently. To achieve these objectives, a comprehensive literature review and pilot interviews with industry experts were first carried out, followed by a survey and post-interviews. The results indicated that the smart technologies with the greatest impact on project management were autonomous vehicles, robotics, cyber-physical system, Internet-of-Things and big data, which were largely contributed by the changes in how information has been collected, processed and utilized, and the automation of work processes. All project management knowledge areas were also found to be impacted by the smart technologies at varying degrees, with perceived differences among organizations of different sizes in several smart technologies on project management knowledge areas. The findings of this study provide better understanding of how the smart technologies impact project management, serving as starting points to anticipate and make necessary changes to project management processes in order to maximize the potential of smart technologies and ultimately improve the performance of the construction industry.

Keywords
Impact of technologies, Project management knowledge areas, Smart technologies

1 Introduction

The technologies of Fourth Industrial Revolution (4IR) enable the convergence of the physical and cyber paradigms, leading to the integration, digitalization and automation of entire value chains (Kamble *et al.* 2018). The integration of entire value chains presents the potential to improve performance of industries, when complemented with streamlined organization and work processes and collaboration within business ecosystems (Leviäkangas *et al.* 2017). While the nature of the construction industry has led to fragmentation and a general resistance towards change, the integration of the construction value chain presents huge potential to improve the performance of the industry (Sepasgozar *et al.* 2016). In particular, effective project management was found to be a critical project success factor and significantly influences project performance (Wanivenhaus *et al.* 2018). However, existing studies on smart technologies in the construction industry typically focus on the specific applications of smart technologies or on improving the performance of the technology applications. Hence, this study aims to provide a better understanding of the impact of smart technologies to allow practitioners to anticipate the changes in project management processes. This study has the following research objectives: (i) investigate the smart technologies with the greatest impact on project management; (ii) assess the specific project management knowledge areas that will be significantly affected by the technologies; and (iii) statistically analyze if organizations of different sizes perceive the impact on project management knowledge areas differently. This study is conducted in the Singapore construction industry to complement the Construction Industry Transformation Map, established by the Singapore government to drive the adoption of smart technologies to improve the productivity and performance of the industry (Building and Construction Authority 2017). The findings of this study will allow organizations and project managers looking to implementing smart technologies to anticipate the changes in project management processes and better prepare themselves and facilitate the digital transformation of the construction industry.

2 Literature Review

Smart technologies associated with the 4IR include Cyber-Physical System (CPS), Internet-of-Things (IoT), Big Data (BD), robotics, Autonomous Vehicles (AV), Augmented Reality (AR), Virtual Reality (VR), Additive Manufacturing (AM), blockchain and laser scanning (Oesterreich and Teuteberg 2016; Kamble *et al.* 2018; Akhilesh 2020). These technologies can be used to digitalise and automate work processes by enabling the self-organisation and self-execution of work tasks, and have been commonly referred to as smart technologies (Akhilesh 2020). These smart technologies can be used in several aspects of construction projects to improve the performance of project management. Project management typically consists of ten knowledge areas as highlighted in project management standards, namely – (i) project integration management; (ii) project scope management; (iii) project schedule management; (iv) project cost management; (v) project quality management; (vi) project resource management; (vii) project communications management; (viii) project risk management; (ix) project procurement management; and (x) project stakeholder management (International Project Management Association 2015; Project Management Institute 2017).

In particular, CPS and IoT may be used for real-time monitoring and control on-site and along the supply chain, enabling the access to real-time project information for viewing, managing, sharing and collaborating from any location (Akanmu and Anumba 2015; Zhong *et al.* 2017). This changes the way project information is collected, processed, analyzed, communicated, and utilized by project stakeholders. BD processes and analyzes large volume, variety and velocity of data, which can impact all project management processes as both real-time and historical project data can be utilized to optimize and automate project processes (Bilal *et al.* 2016). AV and robotics automate work processes which reduces safety risks, improves consistency and changes the way workers interact with one another as dangerous and routine works can be conducted with the assistance of robots or AVs (Oesterreich and Teuteberg 2016; Chen *et al.* 2018). AR and VR enable project stakeholders to explore the 3D model and collaborate with one another, changing the communication medium among project stakeholders (Chi *et al.* 2013; Oesterreich and Teuteberg 2016). AM allows for printing of 3D components based on a digital model, enabling design freedom and shifts work processes off site (Kothman and Faber 2016). Blockchain can be used to automate contract execution upon fulfilment of agreed conditions, improving trust among project stakeholders and enables teams to be formed across geographical borders (Turk and Klinc 2017). Finally, laser scanning can be used to automatically collect 3D geometric information of as-built conditions to develop a 3D model to identify discrepancies of the as-built and as-planned models and site survey (Bosche *et al.* 2009). This can improve the efficiency of site surveys and enables timely identification of discrepancies, reducing reworks (Oesterreich and Teuteberg 2016). A summary of the smart technologies and the knowledge areas expected to be impacted is shown in Table 1.

Table 1. Summary of smart technologies and knowledge areas expected to be impacted

Smart technologies	**Applications**	**Knowledge area expected to be impacted**
Cyber-physical system and Internet of things	Real-time monitoring and control on-site and along the supply chain (Akanmu and Anumba 2015; Zhong *et al.* 2017)	All project management areas
Big data	Analyse real-time and historical project data to optimise and automate project processes (Bilal *et al.* 2016)	All project management areas
Autonomous vehicles and robotics	Automate work processes (Oesterreich and Teuteberg 2016; Chen *et al.* 2018)	Project schedule management, project cost management, project quality management, project resource management, project risk management
Augmented and virtual reality	Enable project stakeholders to explore the 3D model and collaborate with one another (Chi *et al.* 2013; Oesterreich and Teuteberg 2016)	Project integration management, project scope management, project schedule management, project cost management, project quality management, project risk management, project communications management, project stakeholder management
Additive manufacturing	Print 3D components based on digital model (Kothman and Faber 2016)	Project scope management, project schedule management, project cost management, project quality management, project communications management, project risk management, project procurement management, project stakeholder management
Blockchain	Automate contract execution (Turk and Klinc 2017)	Project schedule management, project cost management, project quality management, project communications management, project risk management, project stakeholder management
Laser scanning	Automatically collect 3D geometric information of as-built conditions to develop 3D model (Bosche *et al.* 2009)	Project integration management, project scope management, project schedule management, project cost management, project quality management, project communications management, project stakeholder management

3 Research Methods and Data Presentation

The research process consists of four steps. In Step 1, a literature review was conducted to understand the use cases of smart technologies in construction projects and the impact on project management to develop a survey questionnaire to gather the opinions of practitioners. Pilot interviews were carried out with industry experts to validate the survey questionnaire in Step 2. Step 3 was to administer the survey questionnaire to industry practitioners. The survey was sent to 600 target respondents and a total of 73 responses were received. The survey response rate is 12.1% and is within the norm of Singapore's survey response rate (Liao and Teo 2019). In addition, valid statistical analysis can be conducted as the total number of valid responses is more than 30, where the central limit theorem holds through (Ott and Longnecker 2016). Furthermore, with a sampling frame of at least 500 and at least 50 valid responses, low response rates do not equate to nonresponse bias (Curtin *et al.* 2000; Keeter *et al.* 2000; Fosnacht *et al.* 2017). The survey respondents include project managers (69.86%), architects (23.29%) and directors (6.85%), in which more than half of them (58.90%) have more than ten years of experience in the construction industry. In addition, the organizations comprise of small and medium enterprises (SMEs) (58.9%) and large enterprises (41.1%).

In Step 4, analysis of the responses was conducted through Statistical Package for the Social Sciences (SPSS) to determine the level of impact of smart technologies on project management knowledge areas. Shapiro-Wilk test was used to test the normality of the sample and indicated that the data is non-normally distributed. Mean rank analysis and one sample Wilcoxon-signed rank test were conducted to assess the significance of the impact of smart technologies on project management knowledge areas. To assess if organizations of different sizes perceive the impact on project management knowledge areas differently, the Mann Whitney U test was conducted.

4 Findings and Discussion

Table 2 shows the summary of the results from the mean rank analysis and Mann-Whitney U test among organizations of different sizes. The one-sample Wilcoxon-signed rank test indicated that all smart technologies impact project management knowledge areas, albeit at varying degrees. Based on the mean rank analysis, the smart technologies that have the greatest impact on project management knowledge areas were found to be AV and robotics, CPS and IoT and BD.

The top smart technologies that have the greatest impact on project management knowledge areas were found to be AV and robotics. This finding is expected as the construction industry is one of the industries with the lowest productivity rates due to the high level of uncertainty and reliance on manual labor, and is often known as a "dirty, dangerous, and difficult" industry (Yap and Lee 2020). Highly dangerous and routine works can be automated and conducted by AVs and robots, overcoming the challenges of low productivity and high safety risks. Accordingly, the top project management knowledge areas that were perceived to be impacted by AVs and robotics were found to be project quality, schedule and cost management. Automation of work processes can ensure consistency of works, reducing human errors and influences of fatigue, resulting in improved quality and increased certainty in the prediction of project duration and costs of work tasks (Chen et al. 2018). Furthermore, AVs can enable more holistic monitoring of the projects with the improved access to hard-to-reach or dangerous areas for human workers and consistency of data collected (Chen et al. 2018). However, in order to automate work processes, there may be shifts in workloads towards the detailed planning and monitoring of robotic systems in the earlier project phases (De Soto et al. 2019).

The next top smart technologies that greatly impact project management knowledge areas were found to be CPS and IoT. CPS and IoT were found to impact project communication, stakeholder and integration management the most. This finding is in alignment with the fundamental characteristic of the 4IR, which supports the integration of entire value chains, hence improving communication among stakeholders. Currently, the construction industry is very fragmented, with multiple stakeholders involved in the project operating in an environment with poor information transfer (Fernández-Solís *et al.* 2015). Several revisions of project information may be circulating among the project team, with duplicated or obsolete versions. Hence, the integration of the value chain can greatly improve project communication, stakeholder and integration management, where project stakeholders can now have access to the same updated project information from any location for communication (Oesterreich and Teuteberg 2016). Furthermore, existing construction processes do not support collaboration among stakeholders and require changes in communication processes among project stakeholders (Hwang *et al.* 2020). The digitalized and integrated construction value chain also increases transparency, which can increase trust among stakeholders and further improve project performance (Li *et al.* 2019).

Finally, BD was also found to impact project management knowledge areas significantly. Similar to CPS and IoT, BD was found to impact project communication, stakeholder and integration management the most. This could be because BD may be an enabling technology to support the real-time processing and analysis of collected data in the CPS and IoT network (Oesterreich and Teuteberg 2016). As construction projects are exposed to a high level of uncertainty such as bad weather, material and labour shortages, especially in the early phases of the projects, BD can be utilized to analyze historical project data to aid in project schedule and cost planning. Currently, project schedule development and cost estimation relies heavily on the experience of the planner (Project Management Institute 2017). The availability of data support in the development of project schedule and estimation of project costs can improve the accuracy of the developed schedule and cost budgets as biases based on the past experiences of the schedule planners and cost estimators may be reduced. Besides that, BD also impacts project integration management, in particular, change management, as the effects of project changes on project schedule, scope and risks can be assessed to determine the impact of the project change on overall project outcomes and select an optimal response to project changes (Bilal *et al.* 2016). Apart from the analysis of project information, BD can also enhance data visualization which allows for easier understanding in the decision making process. Overall, BD provides the platform for the project team to make data-driven decisions by executing analysis on historical and real-time data and enhances the visualization of the analysed data to improve communication among the project stakeholders.

The results of the Mann-Whitney U test indicated that SMEs and large enterprises perceived the impact of CPS, IoT and BD on project integration management, AV and robotics on project quality management, and laser scanning on project schedule and quality management differently. In particular, respondents from SMEs perceive the impact of these smart technologies on the project management knowledge areas to be less than large enterprises. While SMEs may have less resources to invest in new technologies, SMEs are typically more flexible and open to innovations to stay competitive (Guo and Cao 2014; Liao and Barnes 2015; Whyman and Petrescu 2015). Large enterprises may have established standard operating procedures to ensure consistency and may perceive the impact to be greater (Sageder and Feldbauer-Durstmüller 2019). Hence, the results are expected as SMEs have to embrace innovations to stay relevant and large enterprises have to uphold their reputation with consistent quality and performance, which may contribute to the differences in the perceived impact of the smart technologies on project management knowledge areas.

Table 2. Summary of the perceived impact of smart technologies on project management knowledge areas

	CPS/ IoT			BD			AV/ Robotics			AR/ VR			AM			Blockchain			Laser scanning		
	M	R	MW	M	R	MW	M	R	MW	M	R	MW	M	R	MW	M	R	MW	M	R	MW
Project Integration Management	4.17	3	0.031*	4.17	3	0.050*	4.13	5	0.554	4.00	1	0.601	4.02	5	0.850	4.13	3	0.953	4.12	2	0.807
Project Scope Management	4.11	4	0.176	4.12	4	0.126	4.11	6	0.597	3.90	4	0.855	4.02	5	0.850	4.11	4	0.868	4.13	1	0.929
Project Schedule Management	3.90	6	0.075	3.86	6	0.292	4.39	2	0.052	3.60	8	0.814	4.41	2	0.102	3.64	6	0.530	3.84	5	0.043*
Project Cost Management	3.63	9	0.873	3.64	9	0.504	4.32	3	0.190	3.50	9	0.685	4.32	3	0.367	3.46	9	0.180	3.46	8	0.293
Project Quality Management	3.76	7	0.407	3.72	7	0.687	4.46	1	0.030*	3.82	6	0.497	4.43	1	0.086	3.53	8	0.780	3.76	6	0.017*
Project Resource Management	3.57	10	0.186	3.53	10	0.165	3.58	8	0.453	3.90	4	0.424	3.50	9	0.477	3.39	10	0.338	3.27	10	0.364
Project Communication Management	4.35	1	0.053	4.37	1	0.120	3.56	9	0.507	3.92	3	0.278	3.27	10	0.516	4.17	1	0.322	4.02	4	0.843
Project Risk Management	3.75	8	0.341	3.70	8	0.058	4.24	4	0.330	4.00	1	0.357	4.17	4	0.065	3.64	6	0.530	4.09	3	0.423
Project Procurement Management	3.98	5	0.632	3.93	5	0.708	3.26	10	0.581	3.27	10	0.800	3.54	7	0.110	3.93	5	0.816	3.30	9	0.800
Project Stakeholder Management	4.31	2	0.279	4.24	2	0.105	3.71	7	0.601	3.74	7	0.504	3.53	8	0.949	4.15	2	0.585	3.67	7	0.844
Mean	3.96	2		3.93	3		3.98	1		3.77	6		3.92	4		3.82	5		3.77	6	

M – Mean, R – Rank, MW – Mann Whitney U Test among Organization Sizes (SME vs Large Enterprise)
* Significant with p-value <0.05

5 Conclusions and Further Research

Smart technologies associated with the 4IR can overcome many of the challenges faced by industries. However, the fragmented nature of the construction industry leads to a general resistance toward change and laggardness in technology adoption. At the same time, this presents huge potential to overcome the specific challenges of the construction industry. To increase the adoption of smart technologies, this study examined the smart technologies with the greatest impact on project management, the impact of the smart technologies on project management knowledge areas and assessed if organizations of different sizes perceived the impact of smart technologies on project management differently. All smart technologies were found to impact all project management knowledge areas at varying degrees, with AV, robotics, CPS, IoT and BD perceived to have the greatest impact on project management knowledge areas. Organizations of different sizes also perceived differences in the impact of several smart technologies on project management knowledge areas.

While the objectives of this study have been achieved, there are some limitations to be considered. This study collected the perceived impact of smart technologies on project management, which may be subject to the respondents' past experiences. Next, the response rate is relatively low and more reliable results may be produced with a larger sample size. Despite the limitations, the findings serve as starting points for construction organizations to prepare for the digital transformation by anticipating the changes to project management processes. This may increase the adoption of smart technologies and ultimately improve the performance of the construction industry. Future studies can be conducted to investigate the specific changes to project management processes according to each application in the construction industry and on the specific competencies required to manage projects incorporated with smart technologies.

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