Impact of Smart Technologies on Construction Projects: Improvements in Project Performance

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Abstract
The lack of awareness of the benefits from adopting smart technologies have led to its low adoption in the construction industry. Hence, this study aims to investigate: (i) the most beneficial smart technologies; (ii) the improvements in project performance from the implementation of smart technologies; and (iii) the correlations among the smart technologies and the improvements to project performance. A literature review and pilot interviews were first conducted, followed by a survey. It was found that the smart technologies that bring about improvements are autonomous vehicles and robotics, additive manufacturing and cyber-physical systems and Internet-of-Things, with projects benefitting most in terms of productivity, quality and collaboration. Several correlations were also found among the rank-order of the perceived benefits and the technologies. The findings allow for better understanding of smart technologies in projects and the improvements in project performance, laying the foundation to facilitate the digital transformation of the construction industry.

Keywords: Smart technologies, Fourth Industrial Revolution, Improvements in project performance, Construction projects, Singapore

1 Introduction

Smart technologies associated with the Fourth Industrial Revolution (4IR) enable the integration, digitalisation, and automation of entire value chains, providing opportunities to improve the performance of industries (Kagermann et al., 2013; Oesterreich and Teuteberg, 2016). Some of the key technologies associated with 4IR include Cyber-Physical System (CPS), Internet-of-Things (IoT), Big Data (BD), Additive Manufacturing (AM), Augmented Reality (AR), Virtual Reality (VR), robotics, Autonomous Vehicles (AV), laser scanning and blockchain (Dallasega et al., 2018; Oesterreich and Teuteberg, 2016; Pereira and Romero, 2017; Stock et al., 2018). These technologies enable the self-organising and execution of work tasks, and have been referred to as smart technologies (Akhilesh, 2020). These smart technologies allow work processes to be optimised according to the conditions of the physical environment, enable mass personalisation, and automate routine and dangerous works, hence improving the performance of industries (Chen et al., 2018; Oesterreich and Teuteberg, 2016; Stock et al., 2018).

While smart technologies can improve the performance of industries, the nature of the construction industry leads to a general resistance towards the adoption of new technologies, resulting in low technology adoption rates (Hwang et al., 2020; Oesterreich and Teuteberg, 2016). In particular, one of the key reasons for the low technology adoption rate may be contributed by the lack of awareness of the potential benefits of the smart technologies, thereby increasing the perceived risks from adopting smart technologies (Ngo et al., 2020). In addition, there are limited studies that investigate the improvements in construction project performance from the adoption of smart technologies. Hence, this study aims to investigate: (i) the most beneficial smart technologies; (ii) the improvements in the performance of construction projects that can be achieved from the implementation of smart technologies; and (iii) the correlations among the smart technologies and the perceived improvements to project performances. The findings provide a better understanding of the feasibility of adopting smart technologies in projects and the corresponding improvements in project performance which can serve as a foundation to develop a data-driven roadmap to drive the adoption of smart technologies in the construction industry, ultimately facilitating the digital transformation of the construction industry.

2 Background

CPS and IoT converge the cyber and physical paradigms through the use of combination of hardware and software components connected to a digital model via sensors, actuators and real-time networks (Lee et al., 2015); BD encompasses technologies that store, process and analyse large volume, variety and velocity of data for decision making support and automation of processes (Ngo et al., 2020); robotics and AV execute programs to complete predetermined tasks (Kato et al., 2015); AR and VR display virtual information into the user's view (Chi et al., 2013); AM builds up successive layers of materials according to a computer-aided drawing model (Kothman and Faber, 2016); blockchain is a data structure that contain transactions logged in a chronological order which is immutable (Turk and Klinc, 2017); and laser scanning captures 3D geometric as-built information to generate 3D models (Álvares et al., 2018). Some of the common smart technology applications in construction projects that may significantly impact project performance include: (i) real-time monitoring and control of labour, materials and equipment on site and along the supply chain; (ii) integrated data platform for decision-making and optimised planning; and (iii) real-time communication, as shown in Table 1.

Through the use of sensors, data of the physical environment can be collected and sent to the digital twin in real-time for processing and analysis to monitor the project progress and trigger pre-determined responses to minimise project risks (Akanmu and Anumba, 2015; Jia et al., 2019). This can also be applied to track materials, equipment and prefabricated components, improving the traceability and trackability of the components, increasing accountability of project participants and ultimately enhance quality (Zhong et al., 2017). These sensors may be attached to robots or autonomous vehicles, automating the data collection process. When used in conjunction with blockchain, contracts can be automatically executed upon fulfilment of the agreed conditions based on the project progress (Turk and Klinc, 2017). The automated data collection reduces human errors and time required for administration tasks, improving information transfer among stakeholders (Oesterreich and Teuteberg, 2016; Riaz et al., 2014). Furthermore, productivity can be improved through timely identification of discrepancies between the as-built and as-planned models (Bosché et al., 2015).

With real-time project information automatically collected and stored in a centralised platform, stakeholders can access updated and integrated real-time project information (Dallasega et al., 2018; Zhong et al., 2017). This can improve collaboration, integration, quality, productivity and material flow throughout the project (Dallasega et al., 2018; Merschbrock and Munkvold, 2015). These data can be analysed against historical project data to determine the optimal action plan to ensure project success (Bilal et al., 2016; Oesterreich and Teuteberg, 2016). Furthermore, historical project data can be used for root cause analysis and prediction of project risks to support decision-making (Bilal et al., 2016). Beyond projects, the centralised data platform can assist organisations in knowledge management to improve organisation performance (Oesterreich and Teuteberg, 2016).

Smart technologies also allow for real-time communication throughout the value chains. In particular, AR and VR can display virtual information into a user's view and allow for user experience (Chi et al., 2013; Golparvar-Fard et al., 2009). This can improve customer understanding of the final design to avoid wasteful changes during project execution (Oesterreich and Teuteberg, 2016; Wang et al., 2014). Customer relationship may also be improved as customers are involved throughout the project lifecycle (Oesterreich and Teuteberg, 2016; Wang et al., 2014). Paired with the latest project information, project stakeholders can more effectively collaborate with one another (Oesterreich and Teuteberg, 2016; Wang et al., 2014). On-site workers can also access detailed task-related procedures so that correct procedures are executed (Chi et al., 2013; Li et al., 2018). Reworks may also be minimised as design changes can be communicated prior to starting work, avoiding errors early (Chi et al., 2013; Li et al., 2018).

Table 1. Smart technology applications in projects and improvements in project performance

Smart technology applications	**Improvements in project performance**	**References**
Real-time monitoring and control of labour, materials and equipment on site and along the supply chain	• Minimise project risks • Improve traceability and trackability of materials, equipment and prefabricated components • Reduce human errors • Improve information transfer among project stakeholders • Timely identification of discrepancies between as-built and as-planned model	(Akanmu and Anumba, 2015; Bosché et al., 2015; Jia et al., 2019; Oesterreich and Teuteberg, 2016; Riaz et al., 2014; Turk and Klinc, 2017; Zhong et al., 2017)
Integrated data platform for decision-making and optimised planning	• Improved access to updated and integrated real-time project information • Data-driven decision making • Improved knowledge management	(Bilal et al., 2016; Dallasega et al., 2018; Merschbrock and Munkvold, 2015; Oesterreich and Teuteberg, 2016; Zhong et al., 2017)
Real-time communication	• Improved customer understanding and relationship • Improved collaboration • Reduced errors and reworks	(Chi et al., 2013; Golparvar-Fard et al., 2009; Li et al., 2018; Wang et al., 2014)

3 Research Methods and Data Presentation

The research process consists of four steps. In Step 1, a literature review was conducted to establish a foundation for the study and the development of the survey questionnaire. 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 assess the perceived improvements in construction projects from the adoption of smart technologies. The collected data were analysed and validated through interviews with experts in Step 4. The survey was sent to 600 target respondents and a total of 73 responses were received, equating to a response rate of 12.1%. The survey response rate is in alignment with the general survey response rate in Singapore of 10 to 15% (Liao and Teo, 2019). The survey respondents included project managers (69.86%), architects (23.29%) and directors (6.85%), where more than half of them (58.90%) of more than 10 years of experience in the construction industry. To analyse the data collected from the survey questionnaire, frequency analysis, rank analysis, and Spearman Rank Correlation Coefficient (SRCC) test were conducted.

4 Data Analysis and Discussion

Table 2 shows the frequency analysis of the benefits of each of the smart technologies in construction projects. The top three smart technologies that were perceived to bring about improvements in construction projects were found to be AV and robotics, AM and CPS and IoT while the top three improvements in construction projects were found to be improvements in productivity, quality and collaboration. These findings are in alignment with the technologies that enable the common applications of real-time monitoring and control, integrated data platform and real-time communication and the associated improvements in productivity, quality and collaboration that can be expected from the applications (Oesterreich and Teuteberg, 2016).

AV and robotics were perceived to be the top smart technologies that benefit construction projects. While CPS and IoT are the representative technologies of 4IR, AV and robotics may be perceived to bring about greater benefits as the implementation is on a smaller scale and requires less changes in work processes. In addition, the construction industry has been recognised as a "dirty, dangerous, and difficult" industry (Yap and Lee, 2020). Dangerous and routine works can be automated and executed by AV and robots, hence improving project performance. AM was also perceived to be beneficial to construction projects, improving project productivity and quality the most. This is expected as project productivity is calculated based on the outputs of on-site manpower and AM is typically conducted off-site in a controlled environment (Kothman and Faber, 2016). The controlled AM production environment also ensures the quality of the 3D printed components. Finally, CPS and IoT can benefit construction projects through the integration, digitalisation and automation of the value chain, improving the collaboration among stakeholders and productivity of the projects. This finding is expected as CPS and IoT enable project information to be collected and stored automatically in a centralised platform, allowing for real-time communication among stakeholders (Oesterreich and Teuteberg, 2016; Riaz et al., 2014). The data collected can also be analysed in real-time, providing stakeholders with a holistic view of the current project progress and recommended action plans to ensure project success.

According to Pereira and Romero (2017), the core of every industrial revolution involves improvements in productivity. Hence, it is expected for the smart technologies to improve the productivity in construction projects. While project cost and schedule may not necessarily benefit from all smart technologies, the productivity of projects may be improved through enhancements in project quality and improved collaboration among project stakeholders, which are also the top improvements in construction projects from adopting smart technologies. The improvements in quality are also expected as automation can reduce human errors and improve consistency of works (Ding et al., 2013; Riaz et al., 2014). In particular, AM and single task robots produce outputs according to the predetermined 3D model or program with precision, and will not be affected by fatigue or human errors (Chen et al., 2018; Kothman and Faber, 2016; Labonnote et al., 2016). As mentioned above, access to updated project and task-related information allows for errors to be avoided early (Chi et al., 2013; Li et al., 2018). Finally, the integration of the value chain improves the collaboration among stakeholders with access to the same information for communication (Dallasega et al., 2018; Oesterreich and Teuteberg, 2016). In addition, AR and VR enable visualisation of the as-planned and as-built models, allowing clients to be involved throughout the project (Oesterreich and Teuteberg, 2016; Wang et al., 2014). Collaboration among project stakeholders can also be improved with blockchain as immutability of the transactions and contracts formed increases trust among the contracting parties (Turk and Klinc, 2017).

Table 3 shows the summary of the SRCC according to the perceived benefits of the smart technologies. The ranking of the perceived benefits for all smart technologies were significantly correlated to the individual technologies, except for AM, which displayed a moderately positive relationship. This reflects the similarity in perceived benefits of all smart technologies by the respondents. The results also suggested that the ranked benefits from adopting CPS and IoT and other smart technologies except with AV and robotics and AM were positively related. Similar correlations were also found between the ranked benefits of BD and the other smart technologies.

These results are expected as the technologies need to be used in synergy to digitalise and automate the work processes across the project lifecycle. However, no statistically significant relationship was found between the ranking of the perceived benefits from adopting CPS and IoT and AV and robotics, which is unexpected as AV and robotics are essential in automating work processes. This could be due to the limitations of the existing AV and robotics systems in replacing human workers (De Soto et al., 2019). Next, significant rank correlations were found between the perceived benefits of AV and robotics with AR and VR and laser scanning. This finding is expected as these technologies can be used together to automate the data collection processes (Moselhi et al., 2020). The perceived benefits of AR and VR were found to be ranked similarly as blockchain and laser scanning. While AR and VR are not typically associated with blockchain, these technologies can be used in conjunction to digitalise and automate the monitoring and control of projects (Hamledari et al., 2020; Li et al., 2019). The ranking of the perceived benefits from adopting AM and laser scanning were also found to have strong positive correlations as laser scanning may be used to identify discrepancies in 3D printed components (Guo et al., 2020; Sitthi-Amorn et al., 2015). Finally, the rank-order of the perceived benefits of blockchain and laser scanning was found to be strongly correlated. This finding is expected as they can be used together to automate contract execution (Hamledari et al., 2020; Li et al., 2019). Overall, the results demonstrate the perceived improvements from smart technologies when used in synergy.

Table 4 shows the summary of the SRCC according to the perceived improvements to construction projects. Significant positive relationships were found between the ranking of the perceived benefits of each technology in improving the overall performance in projects and to reduce labour, save costs and time. This finding is expected as these involve the key constraints of every project (Irfan et al., 2019). Next, technologies that bring about improvements in quality and in safety were found to be ranked similarly. This finding is expected as safety and quality management principles are built on similar management concepts and improvements in quality typically result in improved safety and vice versa (Loushine et al., 2006; Misiurek and Misiurek, 2020). Ranking of the technologies that bring about improvements in quality were perceived to be strongly negatively correlated with those bringing about improvements in collaboration. This finding is unexpected as technologies that improve collaboration among stakeholders should improve quality with reduction in duplicates and reworks due to errors (De Soto et al., 2019). One possible reason could be due to the limitations of the existing contracting systems and attitudes of the project team players that limit the improvements in collaboration from adopting the technologies (Dainty et al., 2001). Technologies that reduce labour and improve sustainability were also deemed to be similar. Reduction in labour is expected to improve social sustainability as workers may be reallocated to more value adding works with safer work environments (De Soto et al., 2019). Digitalised and automated work processes also improve consistency of works and reduce wastes, hence improving sustainability (Oesterreich and Teuteberg, 2016). Next, the ranking of the technologies that bring about cost savings and those that help to save time were found to be strongly positively correlated. This finding is expected as project schedule can affect project costs, including the need to pay for labour and overheads. Hence, cost savings can be achieved together with time savings. Finally, the rank-order of the technologies that improve safety was found to be negatively correlated with those that improve collaboration, which is unexpected. This could be due to the existing poor collaborative environment between main contractors and subcontractors, where main contractors transfer significant risks to subcontractors despite their limited capacity to bear the risks, resulting in poor safety environment of site workers (Akintan and Morledge, 2013).

Table 2. Frequency analysis and rank of benefits of smart technologies in construction projects

Benefits of Smart Technologies	**AV and Robotics**			**AM**			**CPS and IoT**			**Big Data**			**Laser Scanning**			**AR and VR**			**Blockchain**			**Total**	
	N	RT	RB	N	RT	RB	N	RT	RB	N	RT	RB	N	RT	RB	N	RT	RB	N	RT	RB	N	RB
Improve productivity	58	1	4	61	1	2	63	1	1	58	1	4	61	1	2	56	1	6	52	1	7	409	1
Improve quality	54	2	2	56	2	1	45	3	5	43	3	6	49	2	3	46	2	4	30	3	7	323	2
Improve collaboration	32	7	6	29	7	7	55	2	1	53	2	2	44	3	4	43	3	5	49	2	3	305	3
Cost saving	44	3	1	36	5	4	39	4	2	37	4	3	28	5	5	23	5	7	28	4	5	235	4
Time saving	39	4	1	38	3	2	38	5	2	34	5	5	35	4	4	18	6	6	17	5	7	219	5
Improve safety	39	4	1	37	4	2	18	6	6	19	6	4	22	6	5	34	4	3	7	6	7	176	6
Reduce labour	37	6	1	34	6	2	14	7	3	11	7	5	6	7	7	14	7	3	7	6	6	123	7
Improve sustainability	19	8	1	15	8	2	8	8	4	7	8	5	4	8	7	12	8	3	5	8	6	70	8
Total	322	1	-	306	2	-	280	3	-	262	4	-	249	5	-	246	6	-	195	7	-	-	-

N = frequency, RT = Rank by technology, RB = Rank by benefit

Table 3. Spearman Rank Correlation Coefficient between Smart Technologies

	AV and Robotics	**AM**	**CPS and IoT**	**BD**	**Laser scanning**	**AR and VR**	**Blockchain**	**Total**
AV and Robotics	1.000	0.922*	0.635	0.635	0.719*	0.719*	0.620	0.755*
AM		1.000	0.571	0.571	0.738*	0.690	0.551	0.690
CPS and IoT			1.000	1.000*	0.952*	0.905*	0.994*	0.976*
BD				1.000	0.952*	0.905*	0.994*	0.976*
Laser scanning					1.000	0.905*	0.946*	0.976*
AR and VR						1.000	0.874*	0.929*
Blockchain							1.000	0.970*
Total								1.000

*Correlation is significant at the 0.05 level (2-tailed)

Table 4. Spearman Rank Correlation Coefficient between Benefits

	Improve productivity	Improve quality	Improve collaboration	Cost saving	Time saving	Improve safety	Reduce labour	Improve sustainability	Total
Improve productivity	1.000	0.436	0.127	0.450	0.688	0.109	0.147	0.055	0.582
Improve quality		1.000	-0.821*	0.180	0.721	0.893*	0.595	0.607	0.679
Improve collaboration			1.000	0.126	-0.324	-0.857*	-0.541	-0.607	-0.357
Cost saving				1.000	0.782*	0.198	0.545	0.450	0.829*
Time saving					1.000	0.613	0.682	0.613	0.955*
Improve safety						1.000	0.703	0.750	0.679
Reduce labour							1.000	0.991*	0.775*
Improve sustainability								1.000	0.714
Total									1.000

*Correlation is significant at the 0.05 level (2-tailed)

5 Conclusion

Despite the potential to improve performance of industries, the adoption of smart technologies in the construction industry has been relatively low due to the nature of the industry and lack of awareness of the benefits of smart technologies. Hence, this study investigated: (i) the most beneficial smart technologies; (ii) the improvements in the performance of construction projects that can be achieved from the implementation of smart technologies; and (iii) the correlations among the smart technologies and the perceived improvements to project performances. The top three smart technologies that can benefit construction projects were found to be AV and robotics, AM and CPS and IoT and the top three improvements in construction projects are in productivity, quality and collaboration. Several correlations were also found among the ranking of the perceived benefits from adopting each technology and the technologies that may bring about the benefits to construction projects.

While the objectives of this study have been achieved, there are some limitations to note. First, the survey response rate is relatively low at 12.1% and more reliable results may be produced with a larger sample size. The survey is also conducted with industry practitioners within the Singapore construction industry and may vary in other countries. In addition, the survey collected subjective perceptions of practitioners, and may be influenced by one's experience with the technologies. Nonetheless, the findings from this study provides a better understanding of the improvements in construction projects from adopting smart technologies, laying the foundations for future research to develop a data-driven roadmap to encourage technology adoption and facilitate the digital transformation of the construction industry. Future studies may be conducted to understand the specific use cases of smart technologies in construction projects and the challenges and strategies to drive the adoption of these applications.

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