EXPLORING THE POTENTIAL IMPROVEMENT OF QUALITY CONTROL IN THE CONSTRUCTION INDUSTRY WITH THE USE OF DIGITAL TECHNOLOGY

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The construction industry has traditionally relied on paper to manage quality records, resulting in the capture and analysis of data being challenging, preventing historical performance analytics that lead to better outcomes. This research is aimed at critiquing the application of digital technologies for the potential improvement of quality management in the construction phase of civil engineering projects. To address the aim, two objectives emerge. The first is reviewing digital technologies that are available for use in quality control that could assist in the reduction of defects. The second is seeking the viewpoint from construction professionals to develop a quality management framework employing the most applicable digital technologies. In support of the objectives, a qualitative research approach involves multiple sources of data collection, gained from literature and interviews. Participants include digital engineering specialists, designers, main contractors and subcontractors. Applicable digital quality applications are identified as electronic document management systems, personal digital assistants, building information modelling (BIM), mobile construction application products (apps), clash mitigation using BIM, real time performance information, point clouds of as-built construction, three-dimensional vision on mobile phones and barcodes, among others. This holistic and collaborative approach facilitates personnel to make better decisions in the use of quality data. Implications for practice indicated that training, visible use of digital technologies and the provision of an effective common data environment are paramount in instigating digital applications. Employing this digital engineering in the construction phase should encourage the continuing journey to greater automation of the building activities themselves with an improvement in quality and productivity.

Keywords: digital technology, information management, total quality management

INTRODUCTION

The concept of quality assurance has arisen to ensure that customer requirements within a defined level of quality and conformance are achieved (Chan 1996). For the construction industry, digital technology in the form of computer aided design and building information modelling (BIM) has transformed design, however digital engineering is yet to be fully applied in processes concerning site quality within the ISO 9000 family of standards. Information and communication technology (ICT) are

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changing working practices and this development has far reaching implications for construction firms, providing a new challenge in reconfiguring their resources for the new technological processes on large construction projects (Redwood *et al.,* 2017).

To address the potential improvement of quality assurance in the construction industry with the use of digital tools, two main elements emerge in this paper. The first is the review of digital technologies that are available to the construction infrastructure sector for use in the quality metric of performance. The second is seeking advice from construction professionals to develop a quality management framework, employing the most applicable digital technologies for the next 4 years from the initial appraisal.

Therefore, based on this premise, the aim is to undertake a comprehensive explorative analysis of the potential improvement of quality control in the construction phase, with the use of digital technology. This aim should reduce defects, increasing productivity and performance in an industry where the rework is in the region of 5% of total construction costs (Hwang *et al.,* 2009).

The associated literature reviewed, though covering various aspects within digital processes, fails to address the coherent improvement of quality through the application of current digital technology. Consequently, the principal questions in this research focus on the delivery of a digitally connected approach to the management of construction quality assurance to increase industry performance.

The construction industry still relies heavily on paper to manage its processes. Quality control is little different, with paper-based defects lists and quality records the norm. Due to the lack of digitisation, information sharing is delayed. Clients and contractors therefore often work in different versions of reality. The use of paper makes it difficult to apply historical performance analytics that leads to better outcomes (McKinsey 2016). Contractors are aware that inspection data can provide valuable information for constant improvement, but currently do not have processes for feeding back experience from inspections (Lundkvist *et al.,* 2010). To overcome these issues, the industry is beginning to deploy digital-collaboration and field-mobility solutions. This will result in the emergence of an ecosystem containing a digital layer, including blockchain, to manage large scale authentication and verification.

The 'Made Smarter Review', initiated by the United Kingdom Industrial Strategy Green Paper (Made Smarter 2017), promotes the utilisation of industrial digital technologies. Capital returns and quality should improve through increased accuracy and repeatability. Projects are increasingly being managed through online collaborative platforms (Cooper 2018). Such cloud solutions provide the basis for a 'digital ecosystem' with potentially large productivity benefits as construction firms increasingly utilise digital tools to improve company performance.

The ability to effectively process data with the extraction of useful insights has revolutionised society. With the commoditisation of the technology necessary for storing, computing, processing, analysing, and visualising phenomenon known as 'big data', there is immense interest in leveraging such technologies, for improving the efficiency of construction processes, such as quality control (Bilal *et al.,* 2016). Reductions in construction, operational and maintenance costs can be provided by building information modelling. Also, improved performance and quality can be achieved by effectively using this modelling data (Davila Delgado *et al.,* 2017), supporting informed decisions to produce effective actions. Additionally, the concept of BIM has risen rapidly in the field of construction engineering management (Li and

Yang 2017), with the term Level 3 being the collaboration between all disciplines using a single project model. BIM based intelligent site management models combining the internet, three-dimensional scanning, digital construction models, virtual reality and augmented reality are now possible (Yu *et al.,* 2019).

For the use of digital engineering in quality management, information technology (IT) in the form of document management systems is the enabler that links the various electronic processes together. The combination of processes provides valuable insights to achieve productivity improvements, by removing previously unnoticed impediments (Woodhead *et al.,* 2018). The standardisation of these processes between supply chain members is assisted by BS EN ISO 19650-2 that provides information management requirements in the delivery phase of assets (BS EN ISO 19650-2 2018).

The literature reviewed to improve quality assurance contains both methods that begin addressing the limitations of existing processes, and concepts that have not been widely implemented in business applications to further augment productivity. Progressing from the research articles identified, the applications providing increased surety of quality outcome that are not broadly adopted to date in the construction phase of civil engineering projects are listed in Table 1 below.

Reflecting on the literature, a large group of articles, for example, Lin *et al.,* (2016) and Akponeware and Adamu (2017) concentrate on the use of BIM for digital quality assurance, though this process is only one of the potential options available. Whereas Kwon *et al.,* (2014) considers the use of digital applications to reduce defects that bears on the final quality, pursuing the goal of executing a task correctly at the initial attempt. Chen and Kamara (2011) outlining the implementation of mobile computing in construction, note the increase in wireless network transfer speeds, has a great potential to improve on-site information management.

Regarding other papers, Park *et al.,* (2013) provide a highly technical ontology-based data collection template, but construction personnel on site are currently unfamiliar with this technique and yet to master the implementation. Chen and Luo (2014) propose a BIM based quality management model, that to be effective, requires direct field data transfer to the model. At present, this generally does not occur, and is unlikely to happen with the 4-year timeframe for application of digital processes in this research. Also, Dubas and Paslawski (2018) discuss methods for the elimination of construction quality issues with use of these digital solutions and Marsden (2019) provides a useful table of digital quality duties to achieve this aim.

In ‘Understanding the Implications of Digitisation and Automation’ (Oesterreich and Teuteberg 2016), the adoption of Industry 4.0 technologies has far-reaching implications for the whole construction industry, improving productivity, efficiency, quality and collaboration. To handle digital construction, projects need transformation into self-adaptive systems, to enable connections to align with project goals and configure the right workflow (Gangatheepan *et al.,* 2018).

In a case study of ICT innovation on a large hospital project the practicality of implementation is discussed (Davies and Harty 2013). Technical ICT skills are adopted into the construction project through personal relationships and arrangements. Execution is driven by construction project employees, rather than centrally by corporate IT.

Digital Process	Literature/Vendors	Comments
IT enabler / doc management system	BS EN ISO 19650-2 2018	agreement before site works
Personal digital assistant	Chen & Kamara 2011	education & training
Building information modelling	Lin et al 2016	using information element
Mobile & web applications	www.viewpoint.com	cope with high data traffic
Digital inspection & test plan	BIM360 2019	direct link to IT enabler
Clash mitigation using BIM	Akponeware & Adamu 2017	all contractors on one model
Real time performance information	Wang et al 2015	automated site performance
Mixed reality (digital & real)	Kwon et al 2014	vulnerable site equipment
3-dimensional (3D) vision to mobile	www.structure.io	for less exacting site use
Point clouds of as-built work	www.clearedge3d.com	set of data points in 3D
Sensors within manufacture	Akinci et al 2006	if only used once costly
Condition based monitoring	www.pix4d.com	need suitable vantage points
3D geological models	www.leapfrog3d.com	good as information input
Character rigging & animation	www.mixamo.com	more for method statements
Business intelligence	Batrinca & Treleaven 2015	gauge value from site trial
Radio frequency identification	Wang 2008	quality and production data
Photogrammetric vision	Fathi et al 2015	occlusion from obstacles
Machine vision	www.machinevision.co.uk	more for off-site factories
Simultaneous localisation & mapping	Cadena et al 2016	autonomous vehicles issue
1D & 2D barcodes	Chang et al 2013	suitable data connection
Automated construction plant	www.komatsu.com.au	search 'smart construction'
Mobile mapping platform	www.leica-geosystems.com	'mobile sensor platforms'

Table 1: Possible Digital Quality Management Processes

METHOD

For this paper, the qualitative research uses a relativist approach, whereby the views of participants are used to discover the appropriate digital applications for construction phase quality assurance. The qualitative research involves multiple sources of data collection gained from literature and semi-structured interviews. This is followed by analysing the data, to provide a quality management framework of the most applicable technologies. The research gathers information by asking participants to answer open ended questions (Flick 2009). Participants are chosen from designers, main contractors, subcontractors and specialists in digital engineering, of which 25 participants in total contribute to this study. The criteria for selection are also based on knowledge and experience of construction management and quality assurance. The same questions are asked to all interviewees, to obtain measurable data for further investigation. The meetings are transcribed, to ensure accurate records are available for analysis of the data. From the responses received, the research seeks broad patterns and themes.

The output from the direct questions in the interviews are tabulated, to discover the most appropriate digital quality technologies recorded. For other elements of the research, qualitative data analysis coding is carried out, to seek structure to recorded observations. Specific codes for types of participant responses are developed and the resultant data is quantitively organised, with this approach providing a means to introduce interpretations into the qualitative research methodology. Then in the same spreadsheet as for the direct questions, a series of tables present insights from data received, utilising the coded groups of topics from text transcripts. The most popular

processes chosen by the interviewees, are presented in the following Findings and Discussion section. In the same section, the implications of this research to infrastructure projects and construction management are considered. The research criteria principally involve civil engineering projects in the United Kingdom of over £50 million expenditure with a typical programme length of 4 years.

FINDINGS AND DISCUSSION

In Table 2, where the results of the qualitative analysis are presented, 'widely' is considered applications applied in projects by more than 75% of interviewees and 'localised' implementation by more than 50% of interviewees.

Table 2: Digital Engineering Applications

Digital Engineering Application	Widely	Localised	Comment
Information technology enabler	x		common data environment needed
Mobile / tablet as personal digital assistant	x		digitally co-operative site system
Building information modelling	x		little used for quality assurance
Mobile and web applications	x		choice of propriety systems
Digital inspection and test plan (ITP)		x	moves digital engineering forward
Clash mitigation using BIM	x		integration subcontractors' models
Real time performance data	x		as now used in earthworks
Point clouds of as-built work	x		uses light detection & ranging
Precise 3D vision to mobile phone	x		indoor mapping, 3D scanning
Condition based monitoring		x	often better for progress reports
3D geological models		x	underground utility avoidance
Radio frequency identification		x	cost of units to be considered
Photogrammetric vision		x	fusion photos & computer vision
1D and 2D barcodes	x		common for plant identification
Mobile mapping platform		x	use on backpack or drone

The findings of the research from interviewees responses are as follows:

5. The practical applications for site use dependent on developments by vendors who provide products in a simpler format than implied by academic papers. Tier 1 main contractors should work collaboratively with vendors to provide systems in a common data environment with trials of new products on site.
6. The project management plans followed equally by BS EN ISO 19650-2, specific digital engineering plans and digital inspection and test plans are typically the core procedures that act as the starting points to bind the quality assurance data together. Participants from Tier 2 subcontractors appreciate that Tier 1 contractors decide the management plans for each project.
7. To be visible in an electronic format with a connectivity empowered by technology, the data is enabled by a document management system though interface issues exist between legacy systems that current common data platforms only partly resolve.
8. The training and encouragement of site teams including subcontractors in the use of digital technologies is as important as the actual applications themselves. Interviewees were conscious that an awareness of BIM encouraged the use of other digital applications.
9. Though each application has benefits, the real advantage is utilising the data provided in a holistic and collaborative approach across surveying, geographic

information systems, BIM, automation, collaboration, business intelligence and digital mobility. This enables teams to anticipate issues from data and learning, preventing defects occurring by exchanging expertise.

10. Processes being witnessed in use at site level enables personnel to appreciate the benefits of these applications, with a project based digital champion to promote the unfamiliar technologies so that over a time the body of knowledge increases across the industry.

In the synthesis with the literature reviewed, Leung *et al.,* (2008) approach the improvement of quality using real-time communications, by effectively monitoring projects via cameras, providing progress data so that the supply chain can communicate remotely on issues which if unresolved result in defects. In Table 2 containing digital engineering applications, certainly condition-based monitoring, utilising cameras on tower cranes, is following this approach. Hou *et al.,* (2014) in the use of digital technologies for productivity improvement, take advantage of ICT, Radio Frequency Identification (RFID), laser scanning, BIM and augmented reality, with these processes supported by interviewees who are directly involved with site digital technology. The interviewees concur with Wang and Chong (2015), who state that BIM in the construction phase can improve project performance, though it must be integrated with other technologies. Kim *et al.,* (2008) employ personal digital assistants and a wireless web-integrated system for quality inspections. This system is favoured by all participants in this study. Wang *et al.,* (2015) propose integrating BIM and Light Detection and Ranging (LiDAR) for real-time quality control and Wang (2008) recommends enhancing construction quality inspection and management using RFID technology. Both proposals received favourable responses from interviewees.

For a critique of the research, by reflecting both on the literature studied and the transcribed data of the interviewees' conversations, the following is noted:

- Overall impression arises that the on-going process of digitalisation for quality records is irreversible including following facilities management operations.
- Published literature effectively explains and separately promotes the various elements of digital quality control, without providing a co-ordinated project assurance framework embracing all available processes.
- Successful implementation at project level depends on the management of change, as much as the applications themselves.
- Unfortunately, an excellent digital quality assurance process may still involve much rework, if the performance of the workforce in the subcontract packages deteriorates, then leading to a lower return on contractors' capital.
- Participants cautious on the positive outcomes, as concerns exist about other aspects of the industry, such as competitive tendering, encouraging under-resourced contractors, with insufficient fully agreed design information at time of construction with consequent loss of productivity.

From this research for the digital era, the new definition of quality assurance is less about the traditional adherence to drawings and specification, but now conformance to the data within a digital model that is the twin of the physical structure.

The implications for the potential improvement of quality control are as follows:

1 A variety of digitals applications that have matured over many years are available from individual vendors. These technologies operate quite satisfactorily, applying the process is now the issue. The way IT infrastructure

is set up and managed is what makes these digital applications useful, currently these systems on various electronic platforms are not necessarily compatible with each other. The evolution of data consumption is leading towards streaming latest information received on one platform.

2 Within this linked database approach sits the improvement of quality assurance on a project by digital methods. A robust system that ensures successful step by step operations can be created for project teams. Including specific digital processes, in the subcontract requirements for the supply chain, aids instigation. Once a common database is achieved, with Tier 1 and 2 contractor IT requirements in the conditions of contract, then personnel can understand how processes are performing. Also, broken chains where clients and contractors are using different platforms are prevented.

3 For the application of digital processes, competency of use is paramount, consequently suitable education at school and university is required. This occurs alongside company training particularly at a project commencement, to bring both employees and the supply chain on board. As digital applications are at an early stage of implementation on site, initially important for personnel to become familiar by using tablets and mobile phones. It is noted that IT appears very persuasive on a computer screen, accordingly the project team must be capable of providing resilient quality information.

4 Place personnel psychologically in charge of the technology, so there is a sense of owning the process and then encouraging a proactive awareness of digital quality processes. Though concerns exist that will all enterprises willingly take on board these digital processes, or will they have to be coerced into adopting them, especially to gain benefits that accrue from all parties co-operating across a common platform?

5 Digital quality control utilising a geographic information system (GIS) is very close to fruition. Earthworks operations already put this concept into limited practice. It is considered that surveying processes will incur largest change during next decade with a 3D approach to drawings becoming the norm.

6 For effective utilisation in the construction phase, the I (information) in BIM needs to be readily available besides the model. Any study that enhances this information aspect would be advantageous for construction management teams as clients are becoming aware of the benefit of digitally tracking quality.

CONCLUSION

Digital engineering technology is a holistic and collaborative approach that empowers construction management personnel to make better decisions with data. The connected tactic to better information management is delivered through harnessing the specialist technologies and capabilities of business intelligence, BIM, surveying, geographic information systems, automation, collaboration and digital mobility. Within this linked approach sits the improvement of quality assurance on a project by digital methods. Note BIM is one component of this improvement process.

These digital methods for quality assurance are yet to be fully provided in a common data environment. As well, implementation is at an early stage of development. In the most appropriate digital quality engineering applications (Table 2) chosen by interviewees for instigation on site, most are currently only used by specialist departments. Albeit a variety of digital quality applications that have matured over many years are available from vendors. The technology operates quite satisfactorily,

with the published literature tending to analysis separately the various elements supporting this premise, applying the co-ordinated processes is now the challenge.

There are construction processes, such as earthworks, incorporating geo-spatial setting out, already providing improved quality control, utilising digital technology. For both main contractors and subcontractors, the primary goal is presently for staff and operatives becoming familiar with the world of this technology, then using smartphones or tablets to record and transmit the quality data. Particularly at a project's commencement, training actively supported by senior management, is required to bring both employees and the supply chain on board.

The application of digital engineering to quality issues is not only a choice of systems, but also the suitability of IT infrastructure and the body of technical knowledge available in the construction industry. The evolution of data consumption is leading towards streaming the latest information received. The way IT is set up and managed is the enabler, making digital applications useful. Also, once a common database is achieved within Tier 1 and 2 contractor IT outputs and specified in the conditions of contract, then the overall project team can readily understand how quality processes are performing. Consequently, broken chains, where clients and contractors are using different electronic platforms, cumulating in poor communication are prevented.

For academia, the review and enhancement of current education with a feed-back loop to industry encourages the successful promotion of digital technology. The I (information) in BIM needs to be readily available for quality applications during the construction phase. Any study that enhances this information aspect would be very helpful. Also, research should be carried to test the extent to which all these technologies commercially match or improve on the current levels of accuracy for quality control.

The expansion of knowledge from this paper involves four key contributions:

- Awareness of digital quality technology for quality control.
- Provides project teams a quality management framework of digital processes.
- Senior management benefit from the research findings when setting up digital quality assurance systems to assist the improvement of company performance.
- Enabling the journey of digital engineering in the construction phase.

To conclude, digital applications such as 3D models are already prevalent for design. Shortly the growing use of digital technology for quality assurance in civil engineering infrastructure projects will take place, as indicated by the views of the participants. It emerged that facilities management operations are increasingly using digital systems. So, expanding digital engineering research for the actual building works, encourages the automation for the outstanding element of the construction process that to date been unaffected by the recent march of automated technology in other industries, providing improved quality, productivity and return on investment.

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