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EFFECTS OF EMERGING TECHNOLOGIES IN MINIMISING VARIATIONS IN CONSTRUCTION PROJECTS IN THE UK

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Globally, the construction industry is confronted by many challenges, especially iterative cost and time overrun; exacerbated by variations that occur during construction phases. Variation is one of the most controversial issues in construction contracts. Modernising the industry through emerging technologies will minimise variations, including other benefits. This study aims to examine the effects of emerging technologies in minimising the occurrence of variations in construction projects. The study used mixed methods with participants limited to those that have effectively implemented some emerging technologies in their recent construction projects. Findings reveal how the combinations of emerging technologies such as Virtual Reality (VR), drones, 3D Laser Scanning, Building Information Modelling (BIM) and others are proving to be useful tools in preventing the occurrence of variation when implemented correctly. The study findings established some potentials of emerging technologies in the construction industry.

Keywords: construction projects; emerging technologies; variations

INTRODUCTION

Variations in construction projects are described by Soares (2012) as the most controversial issue in construction, and as an epidemic by Ibbs (1997). Variations have been accepted as a matter of practical reality and a necessary evil (Ssegawa et al., 2002). It is often claimed that even the most thoughtfully planned project may experience inevitable changes (O'Brien, 1998). However, no matter how beneficial a variation may appear to a project, its impact may be felt on various aspects of the project, ranging from interruptions to the workflow to project cost overrun. Jones (2001) has discussed the cumulative disruptive impact of variations whose impact on productivity and cost surpasses the actual cost of the changed work. Grossly over-budgeted projects leave construction clients dissatisfied; taxpayers out of pocket, and increase disputes on projects (Egan, 1998). Variation minimisation, therefore, is fundamental to a successful project delivery. It is commonly argued that there are variations in construction that may be beneficial or even reduce final project cost, such variations are somewhat exceptional in practice. Variation, therefore, “is a subject of extreme importance to construction contracts” (Turner and Turner 1999). Hibberd (1986) asserted that variation is the most significant problem in contract management. This study aims to examine the effects of implementing emerging technologies in minimising variations.

Collectively, several technologies are driving changes in architectural, engineering and construction (AEC) industries and can provide faster and effective innovative solutions in managing construction processes. This study seeks to examine the combined influence of emerging technologies in addressing challenges of excessive variation in construction projects. Stasis et al., (2013) identified two streams of existing studies on the subject of variation as one, empirical studies describing causes and effects of variations on construction projects; and two, the development of models for variation management processes. These existing approaches to managing variations in construction are often reactive rather than proactive. Studies that examine the combined impact of emerging technologies in minimising variation are rare. Exploring, therefore, the role of emerging technologies such as BIM, VR, drones, Common Data Environment (CDE) and others in minimising variation is crucial to combating one of the most controversial issues in construction contracts.

Variations are not accidental happenings nor stand-alone problems in construction processes. Root causes of variations are well established in literature. Aside from unforeseen circumstances, at the early stage of a construction project, if the ideas and knowledge that resides in the minds of construction clients in its entirety are uncaptured, variation appears to bridge the gaps. Arain and Low (2005a) recommend that the design stage of construction is the most crucial stage to focus on to minimise variations and problems on site. Clients, design errors, lack of effective communication among project teams, increasing project complexities, incompetent contractors, and adverse weather, among others are causes of variations. When major root causes of variations are addressed early or eliminated, there will be a significant reduction in the total number of variations a construction project will record. This study examines the effects of implementing emerging technologies in preventing the occurrence of variations.

BIM is central in minimising undesirable variations in construction projects by increasing coordination of designs and other construction documents. A wealth of research on BIM implementation and its benefits in the construction process is building up in the Architectural, Engineering, and Construction (AEC) Industry. However, to effectively minimise variations in construction projects, a combination of other appropriate emerging technologies with BIM along the construction process is required. Most clients are very demanding, and construction projects are becoming increasingly complex. The combined impact of BIM and other technologies will potentially drive efficiencies and minimise detrimental changes. Table 4 gives a list of emerging technologies examined in this study. The application of these technologies along construction processes is capable of minimising variations, thereby keeping construction cost and time under control.

LITERATURE REVIEW

Meaning of variation in construction projects

Variation is a change in design, material, scope or method different from what is specified in the initial contract. Variation can be defined, therefore, as an amendment to the basis on which a contract is agreed. Hibberd (1986) stated that “there is no one definition of what is a variation" but referred to variation as any amendment to the original agreement after the contract was let. Joint Contract Tribunal (JCT) Standard Building Contract with Quantities (2016) defined variation as "the alteration or modification of the design, quality or quantity of the works, materials or goods which are not in accordance with the contract". Wambeke et al., (2011) defined it as "the difference between what was planned and what actually happened". Ibbs (1994) defined variations as "additions, deletions, or other revisions within the general scope of a contract that cause an adjustment to the contract price or time". Even in well-planned contracts, it is very likely that variations will still be inevitable. Most construction projects adopt standard forms of contracts that contain clauses that permit a certain degree of changes to the original scope of work as a means of managing the occurrence of variation. The construction industry in the UK is facing a once-in-a-generation opportunity for transformation that will contribute towards addressing many of its challenges. Leveraging technologies for transformation is a significant global trend affecting all segments of human endeavours; no industry of the world is left untouched.

Importance of variation minimisation

Chan and Yeong (1995) argued that minimising variation is one of the prerequisites of keeping the cost within budget and completing the project on time and gave a list of ten strategies that will help in minimising variations. These include, among others, clear and thorough project brief, thorough detailing of design and excellent communication and cooperation among project teams. Variation is a significant source of delays and disruptions (Akinsola et al., 1994), also significant causes of disputes in construction (Perera et al., 2019). Variation to the original work may be necessary and sometimes beneficial, but the magnitude of the impact of changes introduced may not be fully comprehended immediately after the work is executed. Hence, (Ibbs 2012) advocated that authorisation of variations should be done conservatively and with caution.

Ibbs (2012) found that both predictability of productivity and productivity itself deteriorate with an increasing number of variations a project encounters. Ibbs (2012) found that the ratio of the final project cost to estimated project cost is significantly higher than conventionally thought. The author advocated for variation minimisation for excellent productivity performance of construction projects. Arain and Pheng (2007) argued that variation could be minimised when collective action is taken to identify problems early before construction. Ndihokubwayo and Haupt (2009) research revealed that 14% of variation orders are accompanied by wastages, especially those involving modifications to already completed works. Moayeri et al., (2015) developed a model capable of comparing the original model of a building with a revised model by using BIM to visualise the changes and illustrating the ripple effect of the change in architectural, mechanical, electrical and HVAC systems. Variation always increases the capital cost of construction projects. They result in a heavy administrative load because they require many reviews, discussion, and tracking. Keane et al., (2010) discovered that implementing BIM eliminated variations by removing design conflicts, errors and omissions due to incomplete plans and poor representation of the owner's intent. Keane et al., (2010) therefore argued that variations could be avoided or minimised in projects. Table 1 illustrates how variations can be reduced to a single-digit number on different types of projects during construction if technologies are implemented at the inception of contracts.

Table 1: Impact of BIM on variation minimisation by Fan et al. (2014)

No.	Project type	Project size ($M)	No. of change orders
1	Educational	15	7
2	Office	32	2
3	Hospital	231	9
4	Office	120	1
5	Med. Proc.	145	2
6	Educational	61	3
7	Hospital	8	1
8	Educational	78	3
9	Educational	42	2
10	Hospital	96	0

Emerging technologies in construction

It is referenced repeatedly in literature that construction management processes in the UK are old-fashioned. The industry has little desire to embrace technological development when compared to industries such as manufacturing and automation (Writer, 2017). Although such a comparison can be misleading due to the peculiar nature of construction works. However, the productivity level of the construction industry in the UK has been fundamentally flat since 1994. The financial benefits of implementing these emerging technologies are challenging to estimate (Love et al., 2013). Arguably, technologies such as BIM, 3D scanning, mapping and printing, Cloud Computing, Internet of Things (IoT), Artificial Intelligence (AI), VR, Augmented Reality (AR), Robotics, Drones, Autonomous Vehicles, construction wearables and many more have boosted construction processes. Existing variation management processes, as suggested in research, are reactive rather than proactive, this perhaps accounts for perpetual cost overrun in construction projects. Emerging technologies offer perhaps great opportunities to improve construction processes through better design and efficiency.

Digital technologies that are penetrating construction industry are mobile devices loaded with easy-to-use applications, cloud computing, Big data, artificial intelligence, advance analytics, Project management applications, digital collaboration platforms, BIM, Sensors, Internet of Things (IoT), virtual reality and so on. It is common to find less IT- literate site workers preferring highly sophisticated virtual 3D models over paper drawings on sites (Merschbrock and Rolfsen 2016). There is a thriving market for the increasing proliferation of construction-related software and hardware. It is assumed that the use of technology such as VR will minimise client's variations due to its ability to enable clients to interact and better understand designs in the 3D environment through a special headset. Integrating digital technologies in the construction planning process will aid consultants to produce quality contract documents which will potentially eliminate variation in post-contract stages. Mobile devices allowing site workers to share and access critical project information on site are probably the most widely adopted technologies currently. Mbachu (2017) reported that one of the benefits of using apps in construction as the ability to accurately and efficiently price and track variations. Krajacic (2017) described how the use of smartphones was established as a mainstream product on the Crossrail construction site in London. Wong et al. (2018) investigated the role of BIM in preventing design errors and rework. The result found six factors statistically significant with the impact of BIM on design error reduction.

Jamshidi and Parsaei (1995) defined automation as a "technology concerned with the application of mechanical, electrical and computer-based systems to operate and control production". Examples of automation technologies used in construction are 3D scanning, 3D printing, 3D mapping, Robotics, Drones, Autonomous vehicles and construction wearables. Construction robots also include robotic diggers and cranes used in construction sites. Balfour Beatty, a leading construction firm in the UK, predicts that construction sites will be human-free by 2050. It is expected that 90% of labour costs can be saved using 3D printing. 3D printing can print models of buildings, twisted construction forms or a whole small house. 3D mapping enables construction progress monitoring through crane mounted cameras. A programmable machine referred to as a robot (Saidi et al., 2008) will be more suitable for many construction tasks that are repetitive and predictable such as bricklaying, demolition, tiling, and concrete dispensing.

RESEARCH METHODOLOGY

This study used a convergent parallel mixed method approach by utilising both scale and open-ended survey responses and semi-structured interviews. The pragmatic nature of the study informed the choice of mixed research methods. Johnson (2012) advocated for “dialectical pluralism”, an approach that enables researchers to combine ideas from competing paradigms to achieve the research aim adequately. Guba and Lincoln (2005) argued that mixed methodology is very appropriate to 'make perfectly good sense' of many paradigms and to overcome the weakness of single-paradigm approaches (Bryman, 2006). The use of more than one data source is deemed as essential to improve the credibility of the study.

Table 2: Data collected using mixed method design

Method	Type of instruments used	Purpose of data collection
Survey	Multiple choice questions with multiple answers	To access the level of usage of technologies currently in use in the UK.
	Close-ended questions	To measure the collective impact of technologies on variations and its root causes quantitatively.
	Open-ended questions	To measure the specific impact of each technology on participants' projects
Interview	Semi-structured	To establish the impact of technologies in minimising variation from different construction stakeholders perceptive.
		To understand the overall impact of technologies on projects across the UK.

Population sample and data collection

Emerging technologies are gaining traction within the UK construction industry and are becoming valuable tools for project teams and clients. The study population sample consists of clients/sponsors, contractors, BIM coordinators, architects, project managers, service engineers and others that have implemented various emerging technologies in their projects. Various methods were employed to establish contacts with professionals that have practical experience. These methods include document analysis to explore recently completed and ongoing projects; referrals by some study participants; site visits and by attending construction events. Examples of such networking events attended which ultimately led to data collection exercise are London Digital Construction Week in October 2018; various UK BIM Alliance meetings and BIM in Birmingham conference. After initial contact with interested professionals through these events, further communications through telephone calls and emails with contacts culminated to actual data collection. Table 2 is an overview of how data was collected. In addressing credibility throughout the entire research process; the rigorous and transparent manner of how study participants were identified and followed up before actual data collection have been described. Most participants expressed their willingness to support the study further where needed and eagerness to know the findings of the research upon completion.

Table 3: Demographic information of survey participants

Parameter	Category	Number of responses = 70	%
Nature of participants	Client/Sponsor	10	14
	Architect	15	21
	BIM Coordinator	26	37
	Project Manager	4	6
	Quantity Surveyors	4	6
	Service Engineer	4	6
	Other consultants	7	11

Questionnaire design

This study questionnaire was designed into four sections to collect useful empirical data. Section 1 consists of a list of recognised emerging technologies used in the UK construction industry to determine the level of usage. The result of usage is presented in Table 4. This session was designed in the form of multiple-choice questions with multiple answers style. Participants were asked to select technologies they have used from the list, using tick boxes. Responses were restricted to the list provided to streamline and make analysis specific. Section 2 consists of 30 Likert-scale close-ended questions. These questions were drawn around causes/causer of variations from reviews of literature. Section 3 contains open-ended questions designed to capture the empirical impact of technologies used on participants' current and ongoing projects. Only about 50 per cent, however, duly completed this open-ended session of the questionnaire due to time constraints and other reasons such as non-disclosure agreement as cited by some participants. Section 4 was used to capture demographic data. A pilot study was done to test the adequacy of the questionnaire before distribution to the targeted population. Feedback based on the pilot study was incorporated, and necessary adjustments as suggested by experts were made on all sessions of the questionnaire. The job roles of targeted construction practitioners that have effectively implemented some emerging technologies in their recent construction projects are given in Figure 1.

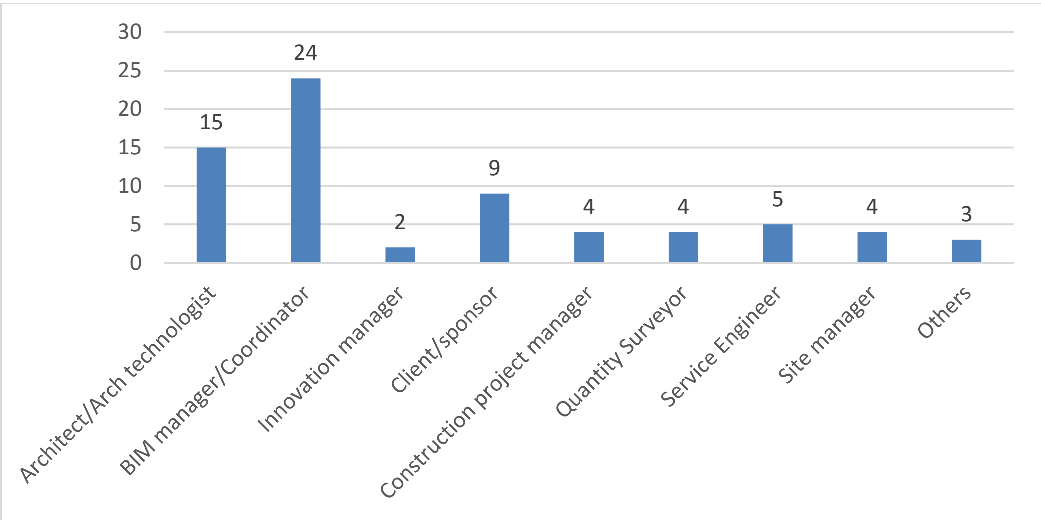

Figure 1: Survey Participants' by role

Semi-structured interviews

Thirty-two semi-structured interviews were conducted over eight months. The purpose of conducting interviews with a wide range of construction stakeholders is to gain a balanced insight into how technologies were utilised, the effects on variation minimisation and the overall projects. The interview questions were tailored to capture these empirical outputs and adjusted to the participant's roles. Semi-structured interviews are regarded as an essential means of collecting data that has a 'direct bearing on the research objectives' (Cohen et al., 2007). Each interview, on the average, lasted for about 45 minutes. For a more comprehensive understanding and to allow participants to be probed, 24 interviews were conducted face-to-face, five were conducted on the phone and three via Skype based on participants' preferences. Proceedings of the meeting were recorded, transcribed and processed using Nvivo

(2012) qualitative data analysis software. On examination and analysis of data, some inductive sub-codes were generated to enrich findings and discussion. For better reliability, the process of member checking was embedded in the data collection process rather than returning to participants to check if transcriptions were correct. Morse (2015) argues that replication determines normative patterns of behaviour, and therefore member checking can be done by presenting quotations of the previously interviewed participants to another. Responses from participants previously interviewed were verified with other participants in the course of data collection. To further maintain the integrity of the analysis, each audio file from the interview was transcribed and reviewed within a week of data collection. Demographic characteristics that provide information about the sampling rationale of selected participants is provided in Figure 2.

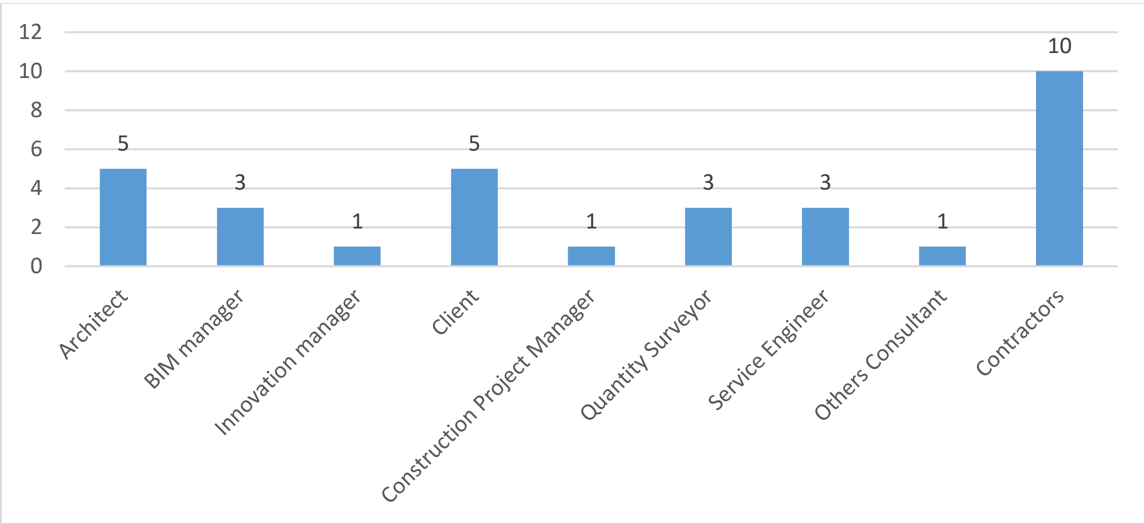

Figure 2: Interview Participants' by role

RESEARCH FINDINGS AND DISCUSSION

Tashakkori and Teddlie (2010) acknowledged that reporting mixed methods research is one of the most challenging tasks due to limited guidance on how to structure a mixed research manuscript. A general summary explaining how research findings will be presented was recommended. Reporting research findings and discussion of this study follows the order presented in Table 2 for clarity and consistency. Each dataset's findings and discussion are presented duly:

The Use of Emerging Technologies

Relative Importance Index (RII) analysis was performed to rank emerging technologies currently in use in the UK based on the data collected from the multiple-choice questions with multiple answers section of the questionnaire survey. The RII value had a range of 0 to 1; the higher the RII value, the more the usage. The result of the RII analysis performed is given in Table 4. The use of BIM ranked first with 0.63 value. BIM is central in minimising undesirable variation in construction projects by increasing coordination of designs and other construction documents. BIM produces digital design information that enables architects, clients and engineers to view, analyse and understand the unbuilt structures. Elimination of ambiguities in these documents minimises variation and allows contractors ‘to build in one build’. Better designs lead to avoidance of rework and demolition, which increases project cost and duration. The use of 3D BIM and smart mobile devices tied in the second rank in usage. Benefits associated with the use of apps with minimisation of variation are swift information sharing, real-time collaboration and better client satisfaction and relationship.

Cloud computing ranked third of the technologies in use with 0.43 value according to findings from this study. The ability to leverage the cloud quickly, inexpensively and easily by construction stakeholders to manage project end-to-end justify the implementation of cloud computing. As highlighted by Perera et al., (2019) that variation-specific dispute may be inevitable in construction, implementing digital collaboration platform such as CDE for example, play a role in minimising such dispute. CDE is a central, single repository that houses all construction project information. Collaboration among remote and geographically dispersed project teams is no longer a challenge in construction when a digital collaboration platform is adopted. Low RII value of technologies such as Artificial Intelligence (AI), Advance analytics, robotics and construction wearables may be a result of usage being very limited to top large construction firms and complex projects presently.

Table 4: Relative Importance Index of use of technologies

S/No.	Emerging Technologies Currently used in the UK Construction Industry	RII
1.	Building Information Modelling (BIM)	0.63
2.	Mobile application software on phones/tablets	0.47
3.	BIM level 3	0.47
4.	Cloud computing	0.43
5.	Digital collaboration platform	0.42
6.	BIM level 2	0.36
7.	3D scanning	0.35
8.	Project management application	0.32
9.	Virtual Reality (VR)	0.31
10.	Spatial measurement	0.23
11.	3D printing	0.22
12.	Drones	0.22
13.	BIM level 4	0.20
14.	Geolocation technologies	0.17
15.	Augmented Reality (AR)	0.17
16.	3D mapping	0.14
17.	Mixed Reality (MR)	0.13
18.	Internet of Things (IoT)	0.10
19.	Big data	0.08
20.	Robotics	0.08
21.	Advanced analytics	0.07
22.	BIM Level 5	0.07
23.	Autonomous vehicles	0.05
24.	Construction wearables	0.04
25.	Artificial Intelligence (AI)	0.04
26.	BIM Level 6	0.03

Findings and discussion from close-ended survey

This section presents the results from close-ended questions of the questionnaire survey. Higher participation among BIM coordinators, architects and clients were expected as participants were limited to those who have effectively implemented some emerging technologies in their recent construction projects. Findings from descriptive statistics analysis show an average mean score of 3.3 with a standard deviation of 1.0 and a variance of 0.9. Further data analysis revealed Cronbach's alpha sigma value of 0.945; meaning that the internal reliability of the quantitative data is high. Wilcoxon homogeneity descriptive statistics test was then performed to compare the results collected face to face and online. The result shows that there is no significant difference between the two data sets. Both data sets were merged for further analysis. Based on the result in Figure 3, 90.0%, 94.3% and 87% of participants agreed that the use of emerging technologies on their projects exposed design errors before construction, enhanced clarity of design before actual construction and potential variations were tackled before construction respectively. Wong et al. (2018) also empirically proved that BIM has the best ability to reduce design errors positively.

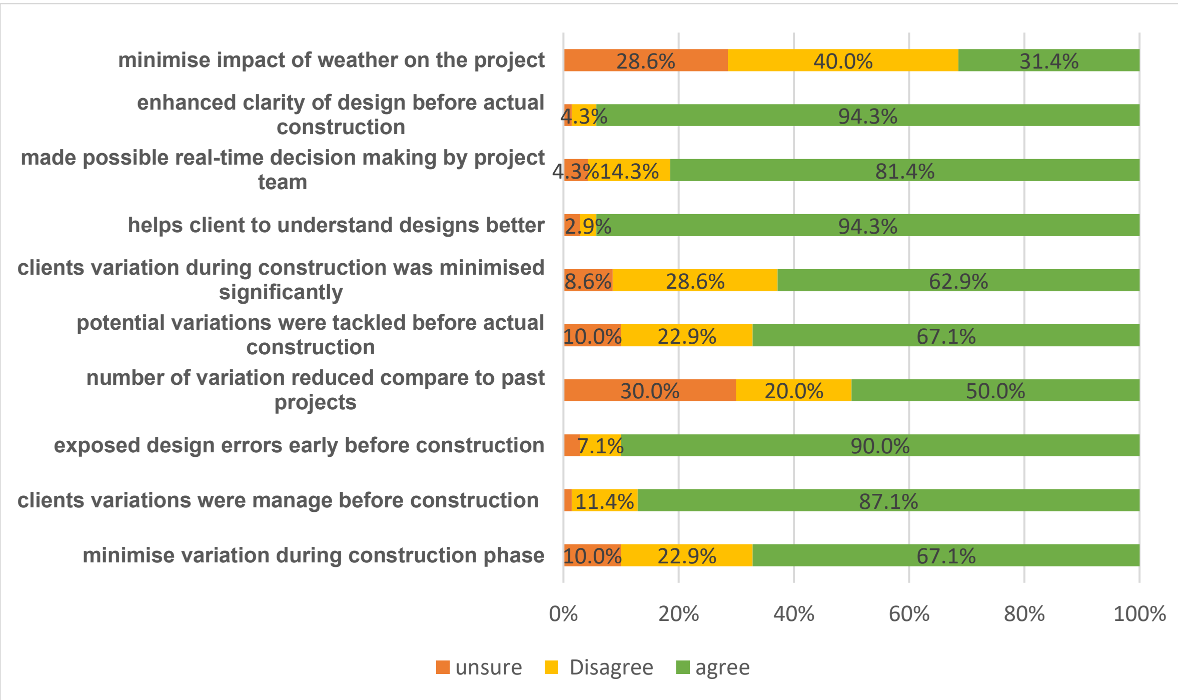

Figure 3: Survey result on the effects of emerging technologies on variations

Technologies remain crucial in proactively minimising variations in construction projects, especially during design stages. Although only about 67.1% agreed that potential issues that could lead to variations were tackled before construction, this percentage is still significant as clients are prone to changing their minds. Construction clients are more demanding and continually changing project designs. Latham (1994) sees the reality of commercial schemes as a dictate of design by construction clients who in turn are responding to external pressures. Findings revealed that 96% of participants agreed that emerging technologies helped the client to understand design better. This suggests that the use of 2D drawings contributes significantly to increase numbers of variations on projects as many construction clients find them challenging to understand and interpret them.

VR allows clients to visualise the entire projects in 3D. It enables clients to interact and understand the unbuilt structure, thereby offering clients the capacity to make changes before construction starts. Study findings confirmed the benefits of VR technologies in providing a three-dimensional view that can be manipulated in real-time. This is useful in exploring and analysing design options, and also in simulations of construction processes (Bouchlaghem et al., 2005). According to Arian et al. (2006), clients will request variations until they achieve project objectives that they have in their minds. Findings show that clients can effectively achieve their business/personal objectives and satisfaction by leveraging emerging technologies rather than raising variation orders during construction to meet their needs. Therefore, study findings demonstrated that the occurrence of variation could be eliminated if their origin and causes are determined and addressed, as suggested by (Awad 2001). Complete elimination of all kinds of variations on construction projects remains a challenge as 40%, and 29% of survey participants disagree/unsure respectively on any impact of emerging technologies on non-technological factors such as inclement weather conditions on their projects.

Findings from the Open-ended survey

Open-ended survey responses from the study gathered more practical information from participants on the effects of different emerging technologies implemented on various construction projects across the UK. Table 5 gives a detailed description of participants' in their own words when asked to list the direct and indirect effects of each technology used in minimising variation.

Table 5: Leverage of emerging technologies on variation collated from open-ended survey

Emerging Technologies	Impact on variation minimisation
BIM	It helps designers to avoid design and human errors in their design. Produces quality design that is buildable by contractors. It allows clients to feel the space and make changes before actual construction. It makes clients get involved throughout the construction process. Gives better control of designs and construction to parties. Integrates clients, designers and contractors in the construction process. Speeds up the design process to produce accurate contract documents Minimises rework, speeds up the decision-making process. Helps manage changes before going to start work on site. Critical to making early decisions. Helps to understand what is needed -materials, labour, and sequence of work An invaluable tool for clients that are not conversant to construction processes. It makes clients get what they wanted exactly. It helps with clash detection and prevention. Remove project risks to enable contractors to make more profit
Virtual Reality	For a better understanding of design, VR immerses clients and other stakeholders in the unbuilt structure. Enables clients to make necessary changes before actual construction.
Smart Mobile Devices	Parties maintain absolute project control Provide a simple instant method of viewing and sharing project documents Improve communication among project teams
Construction Applications	Eliminate paper process thus reduce delay in construction Improves communication and collaboration among project team Enables project tracking in real-time
Drones	Accurate site surveying, site mapping and site inspection for accurate estimations to avoid errors and omissions. Reasons/risks for variation are discovered early through aerial image capabilities Useful for effective project monitoring
3D Laser Scanning	Ensures accuracy of as-built drawings before they turn into variations during construction Reduces requests for information, minimises errors in designs. Comparing design intent to as-built conditions to avoid variation
Cloud computing	Project information security, instant accessibility and distribution of information for quick decision-making. Swift sharing of large project drawings; 3D models information.
Digital Collaboration platforms	Enhance real-time collaboration, swift actions, decisions and approvals Reduce risks and uncertainties that usually necessitate variations.

Findings and discussion from semi-structures interviews

Considering the full range of participants' roles as indicated in Figure 2, interview questions were fine-tuned during the interview process and follow up probing questions were employed where appropriate to ensure questions asked were understood in the way they were intended. Responses from participants, when asked to describe the impact of emerging technologies they have implemented with minimisation of variations, revealed the leverage of BIM, rendering software and clash detection tools in the reduction of design errors. BIM is at the centre of emerging technologies in construction according to study participants. 3D models of designs allow virtual twinning of the structures and quick decision-making process. It enhances the effective management of changes and enables designers to run various design scenarios to meet the required functional and aesthetic needs of clients.

The dominant position of BIM in boosting efficiency and effectiveness of construction projects in the UK notwithstanding, the combine impacts of other appropriate technologies were apparent from interview findings. Utilising collaboration platforms, mobile apps on phone or tablets, cloud computing, CDE led to effective and efficient communication among project teams. Seamless sharing of project information among project teams real-time enhanced decision-making process. It was easy for project teams to identify and trail any laggard members of the team and speed up project delivery. Transparency and security in managing project information were enhanced. Thus, the radical transformation in construction advocated for by Latham (1994) and Egan (1998) is at its cusp.

Responding to the effects of emerging technologies in minimising design errors, a participant said "it goes as far as nine out of ten". In traditional practice, regardless of the experience or educational level of the designer, design errors may still occur. The most frequent reasons for variation are errors in design and incompetent detailed drawings regardless of the procurement method adopted. Lopez and Love (2011) argued that the cost of design errors in various project types, irrespective of the procurement methods, is almost the same. The conventional method of sharing project information through email, especially on large projects, was criticised by participants as a contributing factor to delays and disputes in project management. The use of mobile devices such as smart mobile phones, tablets and cloud computing by project teams provide timely, on-demand access to the latest information and efficient communication. One client said 3D visualisation offered by BIM models did make him feel better about his project because he had a better understanding of the end product.

Also, increased speed of design to meet tight contract duration imposed by many clients stood out as an additional benefit of emerging technologies. Some participants attributed variation orders as down to imperfect or incomplete design inherent with 2D plans and elevations. Even when tight contact duration is imposed, the use of technologies ensure that good quality designs are produced with less chance of missing something out. A participant gave an example of a named project that was delivered end-to-end with technologies. The project was executed almost as a complete paperless project according to the participant. Some participants attested to experiencing a significant reduction in the number of variations recorded at project completions due to the elimination of most project risks, design errors, omissions, rework and effective design coordination. However, some participants pointed out that client-related variations during construction stages still occurred despite technologies adoption.

Findings also revealed that clients who view 3D models with designers throughout the construction process have a far deeper emotional attachment to the finished product than clients who are simply grateful for the finished structure. Many construction contracts are entered by many clients who have little or no experience in construction processes and designs. When the idea and knowledge that reside in the minds of construction clients are not captured in their entirety at the early stage of construction processes, variation appears to bridge the gaps. The use of VR, in combination with BIM, can immerse clients in the unbuilt structure to interact, move and feel the building. Changes can be made, and the immediate effect of the changes can be seen and felt before construction. Participants were asked if technologies used have improved their confidence and their clients' satisfaction with the entire project. Some clients acknowledged technologies used on their projects gave them "total control and understanding of what is happening, what is happening on the project".

Challenges and barriers of variation minimisation

When implemented correctly, technologies simplify construction processes and minimise variations through better integration of project teams. All study participants identified tangible benefits derived on projects with the implementation of emerging technologies. Some participants said despite the considerable investment in technologies such as BIM, CDE and clash detection software on construction processes, some variations were still recorded at the end of their projects. Construction works are majorly outdoor activities, and the atmospheric conditions cannot be controlled or scientifically manipulated. Clients are major causes of variations (Mohammad et al., 2010) in construction projects. A participant stressed that "you cannot get away from your client changing their mind at the last minute". Most variations on projects that implement useful technologies are down to clients' changing needs rather than the designs being incorrect. In projects that adopted the design and build method, few clients that participated in this study complained about contractors' making changes to the original design visualised in BIM, thereby limiting their satisfaction. Some challenges and barriers identified by study participants that are not associated with ‘force majeure’ are listed below:

- Not all project members buy into the use of technologies
- Technologies not working correctly as expected
- Technologies not very useful for small projects
- Benefits limited by design and build procurement route
- Lack of seasoned graduate for immediate employment
- Clients’ changing mind late into projects
- Lack of time to commit to training by construction practitioners

CONCLUSIONS

This study examined the effects of combined emerging technologies in minimising the occurrence of variations. Effects of emerging technologies in minimising variations on projects examined are ascribed to better quality of project designs, reduction of rework, elimination of project risks, useful project information sharing among project teams and swift decision making. Findings also revealed how client-related variations were minimised on various projects examined because clients' brief and intents were captured, reviewed and better presented before construction. Occurrence of variations in construction projects may still appear to be inevitable due to the impact of external factors such as adverse weather conditions and the inability to reject pressing client variation orders that may arise later on in the project. This study findings demonstrated that the implementation of combinations of emerging technologies such as mobile devices, VR, drones, 3D laser scanning, BIM, CDE, cloud computing enhance client satisfaction and minimise design errors. BIM is central in minimising undesirable variation in construction projects; due attention should be given to other emerging technologies springing up that are collectively driving change alongside BIM in the construction industry. Findings paint a picture of an industry seeking to address many of its age-long challenges, especially iterative cost and time overrun, exacerbated by variations that occur during the construction phase.

Although the construction industry in the UK has a reputation for being slow to change, findings from this study point to an industry very much in the transition to an innovative future. Most participants working for large construction and architectural firms did not consider the implementation of emerging technologies as a cost but a saving venture and an effective way of working. Working in a 3D environment offers better collaborative working because digital models contain all the required information to design and construct a building. The impact of emerging technologies is becoming compelling for those yet to adopt them. Traditional 2D drawings are becoming obsolete, and there is less dependence on email for sharing project information on large construction projects. The construction industry needs to pay attention to the challenges identified in the study to maximise the potentials of these technologies in minimising variations.

On successful BIM projects, success is attributed mainly to BIM implementation. However, to effectively minimise variations in construction projects, a combination of other appropriate emerging technologies with BIM along the construction process is required. Thus, the findings of this study provide insight for practitioners and researchers on how current practices may be improved; as well as areas where more research on variation minimisation is needed. There is a great potential for construction projects to continually witness fewer variations as most participants asserted that they are no longer willing to execute any project without implementing technologies they have already embraced. Continuous investment and training of industry personnel are required to reap the full benefits of implementation. The outcome of this study may be useful for construction stakeholders that are considering investments in emerging technologies.

Limitation of the study

It was not possible to ascertain specific numbers of variations recorded on various projects examined in this study.

Disclosure statement

No potential conflict of interest by authors.

REFERENCES

Akinsola, A.O., Potts, K.F. and Ndekugri, I., (1994) Variations on construction projects: A review of empirical studies: Building research and information, 22(5), pp.269-271.

Arain, F.M. and Low, SP, (2005a) Lesson learned from past projects for effective management of variation orders for institutional building projects. In Proceedings of the MICRA 4th annual conference, Kuala Lumpur, Malaysia

Arain, F.M. and Pheng, L. S., (2007) Modeling for management of variations in building projects. Engineering, Construction and Architectural Management, 14(5), pp.420-433.

Arain, F.M., Pheng, L.S., Assaf, S.A. (2006). Contractors' views of the potential causes of inconsistencies between design and construction in Saudi Arabia. Journal of Performance of Constructed Facilities 20 (1): 74-83

Awad, M. (2001) Analysis and Management of Change Orders for Combined Sewer Flow Construction Projects. Unpublished Dissertation, Wayne State University.

Bouchlaghem, D., Shang H., Whyte J., and Ganah A. (2005) Visualisation in architecture, engineering and construction (AEC), International Journal of Automation in Construction, Vol. 14, pg. 287-295.

Bryman, A., (2006) Integrating quantitative and qualitative research: how is it done? Qualitative research, 6(1), pp.97-113.

Chan, A.P.C., and CM Yeong, (1995) A comparison of strategies for reducing variations. Constr. Manage. Econ., 13(6): 467-473.

Cohen, L., Manion, L., and Morison, K. (2007) Research Methods in Education. (6th edition.). London: Routledge.

Egan, J. (1998) Rethinking Construction. Department of the Environment, Transport and the Region, London.

Eigbe, S., (2016) Empirical Study of the Origins and Causes of Variation Orders in Building Projects. International Journal of Engineering Research and Applications, 6(10), pp.34-48.

Fan, S.L., Skibniewski, M.J. and Hung, T.W., (2014) Effects of building information modelling during construction. Journal of applied science and engineering 17(2), pp.157-166.

Guba, E.G., and Lincoln, Y.S., (2005) Paradigmatic controversies, contradictions, and emerging confluences.

Hibberd, P. R., (1986) Variations in construction contracts. London: Collins

Ibbs, C. W., (1994) “Project Change Management.” Construction Industry Institute Special Publication, Austin, Texas.

Ibbs, CW (1997) "Quantitative Impacts of Project Change: Size Issues." Journal of Construction Engineering and Management, 123 (3), 308-311.

Ibbs, CW (2012) "Construction Change: Likelihood, Severity, and Impact on Productivity." Journal of Legal Affairs and Dispute Resolution in Engineering and Construction. 10 (1061), 67-73.

JCT (Joint Contracts Tribunal), (2016). Standard building contract with quantities. Sweet and Maxwell London, UK

Johnson, R.B., (2012) Dialectical pluralism and mixed research. American Behavioural Scientist, 56(6), 751–754.

Jones, R.M., (2001) Lost productivity: Claims for the cumulative impact of multiple change orders. Pub. Cont. LJ, 31, p.1.

Keane, P. B., Sertyesilisik and A. Ross, (2010) Variations and change orders on construction projects. J. Leg. Aff. Dispute Resolution. Eng. Constr., 2(2): 89-96.

Krajacic (2017) Use of IT Mobile Devices on Construction Sites accessed from https://learninglegacy.crossrail.co.uk/article-author/igor-krajacic/ on 8th of March 2019.

Latham, M. (1994) Constructing the Team, London: HMSO.

Lopez, R., and Love, P.E., (2011) Design error costs in construction projects. Journal of construction engineering and management, 138(5), 585-593.

Love, P.E., Simpson, I., Hill, A. and Standing, C., (2013) From justification to evaluation: Building information modelling for asset owners. Automation in construction, 35, 208-216.

Mbachu, J., Mathrani, A., Jones, B. and McDonald, B., (2017) The perceived benefits of apps by construction professionals in New Zealand. Buildings, 7(4), p.111.

Merschbrock, C. and Rolfsen, CN, (2016) BIM technology acceptance among reinforcement workers-the case of Oslo airport's terminal 2. Journal of Information Technology in Construction 21(March), pp.1–12.

Moayeri, V., Moselhi, O., & Zhu, Z. (2015) Design change management using a BIM-based visualisation model [C]. doi:http://dx.doi.org/10.14288/1.0076480

Mohammad, N., Ani, C., Rakmat, RAOK, Yusof, MA (2010) "Investigation on the Causes of Variation Orders in the Construction of Building Project – A Study in the State of Selangor, Malaysia." Journal of Building Performance, 1 (1), 73-82.

Morse, J.M., (2015) Critical analysis of strategies for determining rigour in qualitative inquiry. Qualitative health research, 25(9), pp.1212-1222.

Ndihokubwayo, R., and Haupt, T. (2009). Variation Orders on Construction Projects: Value-Adding or Waste. International Journal of Construction Project Management, 1(2)

O’Brien, J., (1998). Construction Change Orders: Impact, Avoidance, Documentation. McGraw-Hill Professional, New York.

Parsaei, H.R., and Jamshidi, M., (1995) Design and implementation of intelligent manufacturing systems: from expert systems, neural networks, to fuzzy logic. Prentice-Hall, Inc Upper Saddle River, NJ

Perera, BAKS, Ekanayake, B.J., Jayalath, C., and Jayathilaka, G.R.H., (2019) A study on variation-specific disputes that arise in road projects in Sri Lanka: a qualitative approach. International Journal of Construction Management, pp.1-11.

Saidi, K.S., O'Brien, J.B., & Lytle, A.M. (2008) Robotics in Construction. Springer Handbook of Robotics.

Soares, R., (2012) Trust-The Missing Link in Construction. International Journal of Business and Social Science, 3(23).

Ssegawa, J.K., Mfolwe, K.M., Makuke, B. and Kutua, B., (2002) Construction variations: a scourge or a necessity. In Proceedings of the First International Conference of CIB W107 (11-13).

Stasis, A., Whyte, J. and Dentten, R., (2013) A critical examination of change control processes. Procedia CIRP, 11, pp.177-182.

Sun, M., and Meng, X. (2009) “Taxonomy for Change Causes and Effects in Construction Projects.” International Journal of Project Management, 27 (6), 560-572.

Tashakkori, A. and Teddlie, C. eds., (2010) Sage handbook of mixed methods in social & behavioural research. Sage.

Turner, D.F., and Turner, A.E. (1999) 2nd edition. Building contract claims and disputes. Harlow: Longman

Wambeke, B.W., Hsiang, SM and Liu, M., (2011) Causes of variation in construction project task starting times and duration. Journal of construction engineering and management, 137(9), pp.663-677.

Wong, J. K. W., Zhou, J. X., & Chan, A. P. C. (2018) Exploring the linkages between the adoption of BIM and design error reduction. International Journal of Sustainable Development and Planning, 13(1), 108–120.

Writer, I. (2017) Joint workshop tackles emerging technologies in the construction industry, SyndiGate Media Inc., Dubai.