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THE ADOPTION AND EFFECTIVENESS OF MOBILE APPLICATIONS ON SOUTH AFRICAN CONSTRUCTION SITES

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Abstract

Mobile applications have become the primary means of communication, collaboration, and information sharing on South African construction sites. This quantitative study adopted the purposive sampling technique, which included participants from the South African construction industry. Findings indicate that there is minimal awareness and usage of mobile digital technologies on construction sites, and there is a lack of awareness with respect to digital technologies such as building information modelling (BIM). Furthermore, the South African construction industry should leverage the positive benefits of digital technology usage and invest in digital technology for construction management.

Introduction

Collaboration and information integration are indispensable in the development of contemporary digital technologies within the construction industry (Froese, 2010: 533; Schneider and Kokshagina, 2021: 393). The statement thereof is supported by ubiquitous literature and the growing recognition of the reasons for construction project failures, such as low productivity, low predictability, and a lack of collaboration (Li, Greenwood and Kassem, 2019: 300).

Compared to other developing nations, South Africa has experienced a considerable increase in the access and usage of smartphone mobile devices. During a survey conducted in Colombia, India, Jordan, Kenya, Lebanon, Mexico, Philippines, South Africa, Tunisia, Venezuela, and Vietnam, it was determined that a median of 53% of the collective population had access to a mobile device capable of accessing the internet and running mobile applications (Silver *et al.*, 2019: 4).

The construction sector is often among the last to adopt and embrace modern technologies; however, it has been revealed that an effort is being made to change that perception (Igwe, Mohamed and Azwarie, 2020: 15). BIM is positioning itself as the technological 'language' of modern-day design and construction management through its compatibility with Web 3.0's paradigm and futuristic construction methods such as 3D printing and drone technology. It places the construction industry in a position of innovation and is changing the narrative of technology adoption in the construction sector.

BIM and ICT may not be the panpharmacon for the challenges encountered in the construction industry; however, they contribute positively to the overall management experience through their ability to enhance collaboration, communication, and project coordination. Access to hardware and connectivity is low in developing countries (Friederici, Ojanperä and Graham, 2017: 1; Rey-Moreno *et al.*, 2016: 102), however, mobile technologies have made the democratisation of BIM and ICT a realistic milestone.

This study focused on the impact of mobile digital technologies on construction site production activities and the performance expectancy by contractors and professionals in the built environment. The purposive sampling technique was adopted for this study. The statistical analysis of the data revealed a moderate to strong / strong correlation between constructability challenges and inadequate availability of 3D drawings and renderings; a moderate to strong / strong correlation between budget overruns and inadequate digital cost monitoring methods; and a strong to very strong / very strong correlation between schedule overruns and poor methods of communication, information sharing and collaboration.

Overview of the Literature

Digital technology usage in South Africa

There is potential for mobile applications to have a meaningful positive impact on various industries in South Africa due to the population's mobile phone ownership of up to 80% (Chigada and Hirschfelder, 2017: 2). The propagation of mobile applications is a result of the rapid increase in the number of people on the African continent who use smartphones as well as new and different types of mobile devices being introduced to the market (Okonkwo, Huisman and Taylor, 2020: 1577).

BIM's early-stage adoption in Africa might be due to lower access to internet infrastructure (Vaumi, Leudjou, and Faha, 2021: 449) since mobile technology depends on internet connectivity. However, despite South Africa's shortage of a reliable power supply, the literature indicates that initiatives are in place to improve access to the internet and digital technologies (Murugesan, 2013: 8).

The future of digital technology on construction sites

From an organisational digital transformation perspective, it is notable that there has been a transition of interest throughout time from emerging technologies such as text messaging and social media to more complex technologies such as artificial intelligence (AI) and blockchain (Schneider and Kokshagina, 2021: 396).

Scholars are now exploring the use of four-dimensional (4D) digital tools for workspace management on construction sites (Kassem, Dawood and Chavada, 2015: 43). With the aid of BIM, stakeholders would be able to detect workspace conflicts, overlapping tasks and potential design clashes through organised virtual representations of the work environment.

3D printing is gaining momentum in the construction industry. Common use cases include the printing of structural elements for building houses, the printing of concrete casts to create sanitaryware, the printing of components such as conduits and cables (Teizer *et al.*, 2016: 4), and the printing of reinforcement for concrete structures (Tay *et al.*, 2017: 269).

Suppose 3D printing becomes a standardised norm for the construction industry. In that case, it will inevitably rely heavily on BIM models due to BIM's worldwide growing popularity and ability to integrate and exchange design information throughout the project's lifespan (Lee *et al.*, 2019: 878). This reliance positions BIM to influence other types of building technology as well as define future project construction workflows and procedures.

Since both BIM and 3D printing are based on comparable technology (3D computer modelling) and have reciprocal benefits, current research is looking towards standardising their integration for future building projects (Koroteev, Huang and Koreneva, 2022: 2; Tay *et al.*, 2017: 270). BIM's ability to facilitate collaboration among stakeholders and the sharing of design information would ensure a truly integrated framework since construction from the 3D printer would be based on a single 3D model that is shared throughout the lifecycle and among stakeholders of the project (Jiang, 2021: 3).

Digital technology and future legislation

Awareness of BIM is high in most developed countries. Furthermore, the benefits have led to governments encouraging the use of BIM in public projects. As a subsequent result, over fifteen (15) countries worldwide have announced their plans to make BIM mandatory (Tan *et al.*, 2022: 2).

BIM mandates can positively influence the adoption of BIM within a region. The Government Construction Strategy (GCS) in the United Kingdom (UK) mandated the use of BIM Level 2 (the design and storage of 3D models within a collaborative infrastructure) in public projects, which resulted in an adoption rate of close to 70% among construction industry professionals (Al-Hammoud, 2021: 66).

However, the formal establishment of BIM mandate legislation is challenging, time-consuming, and in some cases, unnecessary (Yang and Chou, 2018: 338). There are situations in which the government might not be the central entity responsible for enforcing BIM mandates. In Sweden, BIM mandates originate from the public and private sectors. In the Netherlands, the private sector imposes mandates even in the absence of explicit legislation from the government (Panteli *et al.*, 2020: 4).

Digital technologies and the problems encountered on construction sites

Design conflicts are a frequent occurrence in the construction industry (Akponeware and Adamu, 2017: 4) and have the potential to cause major time and financial overruns (Chahrour *et al.*, 2021: 57). Making use of 3D visualisation software to interpret designs, coordinating the design of all components, and communicating frequently and early with all stakeholders are some of the many ways design conflicts are mitigated or resolved (Kong *et al.*, 2020: 8). Furthermore, incorporating AI in BIM can mitigate conflicts caused by human error (Hsu *et al.*, 2020: 10).

A literature review study that was conducted by Poghosyan *et al.* (2018: 783) concluded that design is one of the primary factors that contribute to accidents and injuries that occur on construction sites. Furthermore, designers' understanding of H&S standards, together with client motivation and regulatory pressure, may encourage designers to pay more attention to minimizing H&S hazards from the design phase of construction projects (Poghosyan *et al.*, 2018: 795).

Some of the most common causes of budget overruns on public South African construction projects are changes in the scope of work, inadequate cost planning and monitoring, incomplete design at the tender stage, project duration extensions, changes in the scope, and delays in pricing variation orders (Tshidavhu and Khatleli, 2020: 124). These overruns frequently result in project delays owing to payment bottlenecks and additional cost increases, both of which have the potential to have a significant negative effect on the stakeholders involved.

During a study conducted by the Construction Industry Development Board (cidb), it was revealed that 9% of the projects that were included in the South African survey had levels of architectural or structural defects that were considered unsuitable (cidb, 2012, cited in Adebowale *et al.*, 2020: 2). Quality plays a pivotal role in the overall performance and success of construction projects (Lou, Xu and Wang, 2017: 669), and technologies such as BIM can help mitigate quality issues faced by contractors and other stakeholders on construction sites (Chen and Luo, 2014: 71); however, digital technologies on their own are not the panacea of the construction industry's quality challenges.

Research Methodology

The purposive sampling technique was adopted for this quantitative analysis study. This sampling technique is suitable for instances where samples are selected based on specific characteristics of the sample group, for a particular purpose (Leedy and Ormrod, 2015: 183).

Built environment practitioners such as architects, construction managers, design engineers, supervisors, site engineers, and skilled / semi-skilled workers who work within the South African construction industry were selected as part of the sample.

The primary data was collected through an online questionnaire and the secondary data was gathered from existing literature and construction industry reports.

The respondents comprised forty (40) individuals in total, consisting of 83% males and 17% females. The respondents had an average age of 36 years and an average of 11 years of experience working in the built environment. 25.6% of the respondents possess a qualification higher than the South African National Senior Certificate (NSC).

Descriptive statistical analysis techniques were used to analyse the data from the research participants. To analyse the responses to sections 1 to 7 of the research questionnaire, the frequencies for each of the responses were represented as a percentage of the total responses. The mean square (MS) of responses to each sub-question was then calculated for each sub-question. The MS provided the central tendency of the data and enabled the further elaboration of the data. The MSs of the responses were calculated using the following formula:

$$MS = \frac{\sum n_i m_i}{\sum n_i - n_0} \quad (1)$$

Where n_i is the variable of interest and m_i the corresponding multiplier. The values of the MSs were then ranked, where a ranking of 1 indicated the highest MS value.

Section 8 of the research questionnaire was an open-ended question. To analyse this data, each response was read, and specific themes were identified. The themes were categorised and represented in terms of frequencies. This provided information with respect to common ideas that the research participants had relative to digital mobile technologies on construction sites. The data from section 9 regarding the demographics of the participants was used to enhance the purposive sampling technique.

The data was further analysed through inferential statistical techniques. The variables were tested for correlation and statistical significance for a 95% confidence level of a one-tailed test. The hypotheses were accepted on the condition that they satisfy both the correlation and the statistical significance test. Spearman's rho correlation coefficient was used to test the correlation since the data is categorical and ordinal.

Table 1 indicates sections of the research questionnaire and the corresponding key information / data gathered from the responses.

Table 1: Sections of the research questionnaire and the key information / data that was gathered

Section	Key information / data gathered
1	Digital technology usage and design clashes
2	Communication methods and design changes
3	Access to 3D renderings and perceptions
4	Frequency of H&S hazards
5	Cost monitoring methods and budget overruns
6	Digital technology usage and schedule overruns
7	Defects and usefulness of digital technologies
8	Perceptions about digital technologies
9	General demographics

Results and Discussion

Salient findings from the descriptive analysis

In terms of digital technology usage, the respondents indicated that text messaging apps (e.g., WhatsApp), and e-mail were used between monthly to fortnightly / fortnightly to share project documentation.

Furthermore, the highest-ranked technologies / methods of communication with people from other disciplines who work on the same construction project were text messaging groups (e.g., WhatsApp groups), followed by face-to-face meetings, voice calls, private text messaging apps, and email correspondence. The MSs indicated that the technologies / methods were used between fortnightly to weekly / weekly.

In terms of methods of cost monitoring, physical documents (e.g., notebooks or receipt books), ranked the highest and were used between fortnightly to weekly / weekly during construction projects. More complex methods such as specialised cost monitoring software ranked the lowest.

The research participants indicated that programme activity / task completion dates were missed between sometimes to often / often. However, practical completion and final project completion dates were missed between rarely to sometimes / sometimes. In terms of digital technology usage, more complex technologies such as BIM, project management app and software ranked the lowest. This further indicates a low rate of digital technology adoption on South African construction sites.

Generally, the research participants indicated low awareness of BIM, despite acknowledging the usefulness of 3D renderings during the construction phase.

Hypothesis testing

Spearman's correlation is a non-parametric test used to assess the strength of association between two (2) variables and is ideal for categorical ordinal data in this case (Hauke and Kossowski, 2011: 87). The formula for calculating Spearman's correlation coefficient is:

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

Where n is the number of data pairs and d the difference between the ranks of the data pairs. If there are two or more data pairs with the same rank, the full version of Spearman's rho coefficient is used:

$$\rho = \frac{\sum_i (x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_i (x_i-\bar{x})^2 \sum_i (y_i-\bar{y})^2}} \quad (3)$$

Where x_i and y_i are the values of the ranks, and $\bar{x}$ and $\bar{y}$ the corresponding means of the ranks. Table 1 below indicates the interpretation of the results based on the value of Spearman's rho coefficient.

Table 2: The value of ρ and the corresponding meaning (Schober, Boer and Schwarte, 2018: 1765)

The absolute value of ρ	Interpretation
> 0.00 ≤ 0.10	Very weak correlation
> 0.11 ≤ 0.39	Weak correlation
> 0.40 ≤ 0.69	Moderate correlation
> 0.70 ≤ 0.89	Strong correlation
> 0.90 ≤ 1.00	Very strong correlation

Depending on the confidence level and the number of data points, a correlation coefficient for the null hypothesis is found. For this study, a confidence level of 95% (α = 0.050) forms the basis for the determination of the data's statistical significance. The calculated value of ρ must be equal to or higher than the corresponding value from Table 3 for the correlation to be accepted as statistically significant using a one-tailed test.

Table 3: Extract from the table of critical values for Spearman's correlation (Gauthier, 2001: 360)

Number of data points	Level of significance (α) 1-tailed test			
	0.100	0.050	0.025	0.010
4	1.000	1.000	-	-
5	0.800	0.900	1.000	1.000
6	0.657	0.829	0.886	0.943
7	0.571	0.714	0.786	0.893
8	0.524	0.643	0.738	0.833

The hypotheses and corresponding outcomes

Hypothesis 1: The conflict among multi-disciplinary outputs is a result of inadequate mobile digital inter-disciplinary coordination and collaboration.

The combined responses related to digital technology usage (DTU), and the occurrence of design clashes (OOC) were considered. The frequencies of the responses were summed and ranked accordingly.

Table 4 represents the summary of the data, with rankings from 1 to 5, where 1 is the highest frequency and 5 is the lowest.

Table 4: Spearman's rho correlation coefficient table for Hypothesis 1 testing

Response	DTU Rank	OOC Rank	d	d^2
Never	1	2	-1	1
Monthly	4	1	3	9
Fortnightly	5	3	2	4
Weekly	3	4	-1	1
Daily / hourly	2	5	-3	9

From the value of ρ (- 0.2), Hypothesis 1 failed the correlation test. There is a very weak to weak correlation / weak correlation between multidisciplinary design conflicts and mobile digital interdisciplinary collaboration. Furthermore, from the table of critical values (Table 3), the critical value for five data points and a confidence level of 95% is 0.900. Therefore, the trend is not significant for a 95% confidence level, and thus Hypothesis 1 was rejected.

Hypothesis 2: Multi-disciplinary outputs that are incomplete and require revision are a result of inadequate mobile digital inter-disciplinary communication.

To test this hypothesis, the combined responses related to the rate of mobile digital inter-disciplinary communication (ROC) and the rate of revisions (ROR) were considered, as summarised in Table 5.

Table 5: Spearman's rho correlation coefficient table for Hypothesis 2 testing

Response	ROC Rank	ROR Rank	d	d^2
Never	1	1	0	0
Monthly	4	2	-2	4
Fortnightly	5	3	-2	4
Weekly	3	4	1	1
Daily / hourly	2	5	3	9

For the value of ρ (0.1), Hypothesis 2 failed the correlation test, there is no correlation to very weak correlation / very weak correlation between ROC and ROR. Furthermore, the trend is not significant for a 95% confidence level, and thus Hypothesis 2 was rejected.

Hypothesis 3: Constructability challenges on construction sites are a result of inadequate 3D visual representations of design outputs.

The participant's ability to plan the construction process from 3D renderings formed the basis of this analysis. It is noted that the basis for this analysis does not cover the complete scope and definition of constructability, however, the built-environment practitioner's ability to understand and plan the construction process serves as a useful indicator of constructability (Nascimento *et al.*, 2017: 1100; Samimpey and Saghatforoush, 2020: 577).

The combined responses related to the availability of 3D renderings (3DA) and the ability to plan the construction process (PCP) were considered, as summarised in Table 6.

Table 6: Spearman's rho correlation coefficient table for Hypothesis 3 testing

Response	3DA Rank	PCP Rank	d	d^2
Strongly disagree	4	5	1	1
Disagree	3	4	1	1
Neutral	5	3	-2	4
Agree	2	2	0	0
Strongly agree	1	1	0	0

From the value ρ (0.7), there is a moderate to strong correlation / strong correlation between 3DA, and PCP, for a monotonically increasing function. Therefore, Hypothesis 3 passed the correlation test. However, the trend is not significant for a 95% confidence level, and thus Hypothesis 3 was rejected.

Hypothesis 4: Inadequate digital 3D visualisations result in H&S hazards.

The combined responses related to the availability of 3D renderings and drawings (3DA) and the occurrence of FFH hazards (FFHH) on construction sites were considered, as summarised in Tables 7 and 8 below. Since both types of data are ordinal, the values of the responses are compared as per Table 7.

Table 7: Assigned values from related questionnaire responses to evaluate Hypothesis 4

Response (3DA)	Response (FFHH)	Value
Strongly disagree	Never	1
Disagree	Bi-monthly	2
Neutral	Monthly	3
Agree	Fortnightly	4
Strongly agree	Weekly + daily	5

Table 8: Spearman's rho correlation coefficient table for Hypothesis 4 testing

Value as per Table 7	3DA Rank	FFHH Rank	d	d^2
1	4	1	3	9
2	3	3	0	0
3	5	4	1	1
4	2	5	-3	9
5	1	2	-1	1

From the value of ρ (0), there is no association of ranks between 3DA and FFHH on construction sites. Therefore, Hypothesis 4 failed the correlation test. Furthermore, the trend is not significant for a 95% confidence level, and thus Hypothesis 4 was rejected.

Hypothesis 5: Inadequate digital monitoring of costs results in budget overruns.

The combined responses related to cost monitoring technology usage (CMTU) and the occurrence of budget overruns (OBO) on construction sites were considered, as summarised in Tables 9 and 10 below. Since both types of data are ordinal, the values of the responses are compared as per Table 9.

Table 9: Assigned values from related questionnaire responses to evaluate Hypothesis 5

Response (CMTU)	Response (OBO)	Value
Never	Never	1
Monthly	Rarely	2
Fortnightly	Sometimes	3
Weekly	Often	4
Daily	Always	5

Consider Table 10 below. Two values under CCMU have tied rankings. therefore, the full Spearman's rho coefficient formula was used.

Table 10: Spearman's rho correlation coefficient table for Hypothesis 5 testing

Value as per Table 9	CMTU Rank	OBO Rank	$(x_i - \bar{x})$	$(y_i - \bar{y})$
1	1	4	-2	1
2	5	2	2	-1
3	3.5	1	0,5	-2
4	3.5	3	0,5	0
5	2	5	-1	2

From the value of ρ (- 0.72), there is a moderate to strong correlation / strong correlation between CMTU and OBO. Therefore, Hypothesis 5 passed the correlation test. However, the trend is not significant for a 95% confidence level, and thus Hypothesis 5 was rejected.

Hypothesis 6: Schedule overruns and delayed deliverables are attributed to poor methods of communication, information sharing, and collaboration.

The combined responses related to communication, information sharing and collaboration (CISC), and the occurrence of schedule overruns (SO) on construction sites were considered, as summarised in Tables 11 and 12 below. Since both types of data are ordinal, the values of the responses are compared as per Table 11.

Table 11: Comparison of ordinal data to test Hypothesis 6

Response (CISC)	Response (SO)	Value
Never	Never	1
Monthly	Rarely	2
Fortnightly	Sometimes	3
Weekly	Often	4
Daily + hourly	Always	5

Table 12: Spearman's rho correlation coefficient table for Hypothesis 6 testing

Value as per Table 11	CISC Rank	SO Rank	d	d^2
1	1	5	4	16
2	4	3	-1	1
3	5	1	-4	16
4	3	2	-1	1
5	2	4	2	4

From the value of ρ (- 0.9), there is a strong to very strong correlation / very strong correlation between CISC and SO. Therefore, Hypothesis 6 passed the correlation test. Furthermore, the trend is significant for a 95% confidence level, and thus Hypothesis 6 was accepted.

Hypothesis 7: inadequate 3D visualisations, access to design specifications and details result in architectural snags.

The combined responses related to the occurrence of design defects (DD), and the availability of 3D visualisations, specifications, and details (3DAS) on construction sites were considered, as summarised in Tables 13 and 14 below. Since both types of data are ordinal, the values of the responses are compared as per Table 13.

Table 13: Ordinal data and corresponding values for assessing Hypothesis 7

Response (DD)	Response (3DAS)	Value
Never	Strongly disagree	1
Rarely	Disagree	2
Sometimes	Neutral	3
Often	Agree	4
Always	Strongly agree	5

Table 14: Spearman's rho correlation coefficient table for Hypothesis 6 testing

Value as per Table 13	DD Rank	3DAS Rank	d	d^2
1	3	5	2	4
2	2	4	2	4
3	1	3	2	4
4	5	2	-3	9
5	4	1	-3	9

From the value of ρ (- 0.5), there is a weak to moderate correlation / moderate correlation between 3DAS and DD. When the availability of 3D visualisations, design specifications, and drawings decreases, the occurrence of defects on construction sites increases moderately. Therefore, Hypothesis 7 passed the correlation test. However, the trend is not significant for a 95% confidence level, and thus Hypothesis 7 was rejected.

Discussion and salient findings

From the descriptive statistical analyses, the study revealed that there is minimal awareness and usage of mobile digital technologies on South African construction sites, at least within the sample group. There is almost no usage or awareness of BIM, even among some professionals within the sample group. There is limited usage of applications or software for construction management on South African construction sites during the production phase. Text messaging applications such as WhatsApp are typically used as the primary means of communication, collaboration, and information sharing.

During the testing of the hypotheses, out of the seven (7) hypotheses, only one (1) was accepted. Three (3) of the rejected hypotheses were rejected on the basis that there was no correlation between the variables. The other three (3) were rejected because they did not pass the test of statistical significance for a 95% confidence level, despite a moderate and strong correlation between the variables.

The data made sense and was consistent. The consistency is first seen in the descriptive analysis of the study, where the responses to questions that are related do not contradict each other.

The consistency of the data is further illustrated in the hypothesis testing of the study. The correlation of the variables made sense directionally. In other words, considering Spearman's rho correlation coefficient of Hypothesis 6 (- 0.9), it would be expected that if there was less communication, there would be more schedule overruns and delays observed. This conclusion, which makes sense on its own, was validated by a purely statistical approach.

Conclusion

The findings indicate a strong correlation between constructability and the availability of 3D renderings and drawings. It is therefore recommended that clients, construction managers, and construction business owners in the South African construction industry insist on gaining full access to 3D renderings and drawings for built-environment practitioners who are based on construction sites. Furthermore, it is recommended that designers such as architects and structural engineers prepare 3D renderings and drawings for all design outputs. The literature suggests that the implementation of digital infrastructure for construction projects can improve the overall performance and productivity of stakeholders involved in the built environment. Therefore, the South African construction industry should leverage the positive benefits of digital technology usage and invest in digital technology for construction management. Furthermore, the findings indicate that communication, collaboration, and information sharing play a crucial role in mitigating schedule overruns. Incorporating digital mobile technologies, such as apps, on construction sites has numerous advantages. Apps can facilitate better communication between team members and stakeholders, regardless of their location. This can aid in reducing misunderstandings and errors and ensuring that all parties are kept up to date with the latest information.

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