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Critical Barriers to the Adoption of Cloud-Native Platforms for Real-Time Construction Monitoring Evidence from Islamabad, Pakistan

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ABSTRACT

The construction industry is shifting to the use of data-driven models of delivery where real-time monitoring can assist timely decisions, increase transparency, and better project results in line with the human-centered and sustainable transformation agendas. The implementation of the real-time control of construction allows monitoring specifics by means of the IoT sensing and constant data capture, which allows transferring construction control into the sphere of the active regulation instead of reactive reporting, although the implementation opportunities in the context of the developing-city conditions remain limited by the gaps in multi-layer readiness. Cloud-native systems, created based on layers of scalable, modular, and resilient architectural principles, provide a promising base of real-time monitoring, as they have the capacity to provide distributed stakeholder access, fast report cycles, and link with digital construction life cycles. Although there are these advantages, not many people adopt the technology in Islamabad because of the technical, organizational, and ability factors that are intertwined together, and the lack of local-grounded implementation channels. This paper examines the issues of adoption and opportunities of using cloud-native platforms to real-time monitor the construction in Islamabad through a quantitative research design built on literature synthesis and query questionnaire survey of the construction professionals. One hundred and fifty questionnaires were distributed, a total of eighty five responded to and then eighty one of these were deemed as valid to conduct statistical analysis. Assessment of reliability and data appropriateness was done using proved survey analysis and non-parametric tests were used in cases where the assumption of distribution was not realized. The Relative Importance Index was used to prioritize adoption factors to identify the most impactful drivers and barriers in the adoption of the most effective fares and the group comparison testing was used to test the perception difference between the stakeholder categories. The results are that the perceived opportunities are high, specifically, the increased transparency between stakeholders, better documentation and reporting practices, faster execution, and the increased sustainability monitoring, though the adoption is mostly limited by the constraints of governance and capabilities, in particular, the absence of organizational policies, the lack of trained personnel, the underdeveloped training programs, the unavailability of the IoT/sensing infrastructure, and the absence of standardized digital monitoring guidelines. According to the prioritized outcomes, the study will suggest a situational implementation framework, translating the topmost factors into a sequentially progressive action steps incorporating governance standardization, workforce

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capability creation, generating infrastructure, and scaled-deployment. The research provides both an empirical insight into cloud-native monitoring adoption in the construction environment in Pakistan and also provides an achievable route towards enhancing efficiency, accountability, and sustainability in construction projects monitoring.

Keywords: Cloud-Native Platforms, Real-Time Construction Monitoring, Construction Digitalization, IoT-Enabled Monitoring, Technology Adoption, Relative Importance Index (RII), Kruskal–Wallis Test.

Introduction

The construction sector is experiencing a digital transformation at very fast pace around the globe due to the growing within and impact of the Internet of Things (IoT), cloud computing, and real-time data analytics in the project delivery processes [1]. These technologies have been mostly linked with high productivity, decreased delays, better safety performance and more sure decision-making more so, in the context of large-scale and complex projects where the standard supervisory practices are usually too slow to spot the deviations and correct the risks in due time [2]. The real-time construction monitoring systems, specifically, utilize sensors, positioning technologies and digital connected platforms to capture the stream of continuous data related to labor activity, material movement, equipment use, and weather conditions to make project teams less dependent on retrospective reporting and more proactive control [1, 2]. Similarly, the development of cloud-native computing has made the viability of scalable monitoring services even more compelling, through the ability to implement modular, fault-tolerant, and dynamically scalable, typically high-volume, time-wary of real-time data flows, using periodic backups and snapshots [3].

Although the existing application of cloud in construction has centered around centralized data storage goals and collaboration objectives, cloud-native platforms extend this functionality by prioritizing architecture goals, including microservices and containerization (e.g., Kubernetes), to increase scaling of monitoring services, resiliency during failures, and adaptability in response to constant changes without adversely affecting operations [3]. Real-time systems often make use of heterogeneous data sources, changing workload needs (e.g., sensor bursts, image uploads), and multi-stakeholder access needs, which are particularly relevant to real-time construction monitoring due to the heterogeneity of such property and the inefficiency of supporting its requirements by conventional monolithic systems [4]. Additionally, the cloud-based building information modeling (BIM) and progress management studies show that the integration of real-time information into the cloud-based workflows would allow re-engineering project control processes to enhance the coordination process, reduction of reporting time, as well as reliability of the performance tracking between stakeholders [5]. These advantages are not just technical enhancements, but they directly affect the governance of the project, enhancing traceability, responsibility, and responsiveness, in environments that are defined by the brokenness of decision making and complexity of contracts.

The argument of real-time and cloud-enabled monitoring is becoming a strong one in Islamabad because of fast urban sprawl, more high-rise buildings and mega-projects,

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and the need to have efficient control in the crowded and complex urban building industries [6]. However, even with this development in construction, the current mode in monitoring Islamabad practices are mostly traditional and reactive, where monitoring is often done through manual site visits, paper records, and tardy or erratic information transfers between the contractors and clients with consultants [7]. This operating state of affairs is known to add to inefficiencies, safety risks, and low transparency of projects, as well as undermine capacity of decision-makers to act early, when productivity bottlenecks, quality defects, or schedule risks crop in [8]. The ensuing mismatch between the rising complexity of projects and the continued use of manual types of monitoring points to the fact that the move to cloud-native real-time monitoring is not merely a case of upgrading technology but is a structural decision in the optimization of governance and performance in the dynamic construction industry in Islamabad.

Although real-time monitoring technologies have been identified to have potential, both construction specifically and specifically in the setting of developing cities, it is limited by multi-layer readiness factors which surpass the availability of technology [9]. Experimental and literature-based projects are all consistent on defining adoption barriers that reside at technical (infrastructure and interoperability), organizational (policies, leadership commitment, change management), and human ability (skills, training, and digital literacy) levels, implying that digitalization of construction is unsuccessful when the enabling conditions are not institutionalized as a standard set of project controls [10]. Digitalization studies with a Pakistan focus also reinforce the idea that adoption of such sectors should be coordinated by taking measures with policy as well as capability-based building processes, and organized implementation channels and not as a technology pilot which still relies on personalized efforts . In line with this, the Islamabad context offers unique impediments restricted icons sensing preparedness, lack of professional training, ineffective training strategies, and lack of agreement modeled observing guidelines and digital transformation journeys that altogether obstruct the transformation of identified advantages into orderly execution [11].

The current research is inspired by this research gap and sets out to examine the use of cloud-native technology in real-time construction monitoring in Islamabad based on a systematic, evidence-driven methodology. The research questions to address include (i) to (ii): The research seeks to classify and identify the most critical challenges that are likely to impact cloud-platform adoption, (ii) formulate strategies to be put in place to enhance the readiness of construction projects in Islamabad to adopt cloud-native monitoring systems, and (iii) develop context-sensitive structure that offers a viable roadmap to be used to implement cloud-native monitoring systems in Islamabad construction projects. The study has a methodological basis on a systematic literature review and the empirical survey of construction professionals to measure the perceived barriers and opportunities, rank them priority-afraid techniques, and transform the most primary ones into the action of implementation. The study includes contributions to the literature on the construction digitalization as the framework is based on the prioritization of the stakeholders, which will provide the empirically supported information about the adoption of cloud-native monitoring in Pakistan and will also be helpful in guiding the work of the policymakers, the

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regulators, and the project organization in question to achieve the most efficient, transparent, and sustainable results with the help of the modern monitoring systems.

Literature Review

The digital transformation of construction has been accelerated due to the search of the project stakeholders to minimize information delays, enhance accountability, and advance decision-making under high uncertainty and complexity in operations. Since weak visibility of actual site conditions and ineffective feedback loops are closely associated with poor performance in construction projects, robust literature on the topic in recent times suggests that construction performance issues including timeline slippage, reworking, accidents, and ineffective coordination are closely connected to these factors [12]. The real time monitoring is thus gaining status as a viable system of enhancing the control of construction due to its capability to facilitate unremitting recording of the site status and allows detection of deviations earlier before they convert to significant delays or claims. Simultaneously, the shift to more human-friendly and sustainability-oriented construction futures insists on the notion that the digital systems are to help enhance the governance, resilience, and transparency, as opposed to automating the processes [13]. In this case, real-time monitoring can be both a technical skill and a social-organizational change that changes how evidence is made, shared, and trusted across the project's network.

Real-time construction monitoring is generally perceived as a systematic gathering and analysis of the project data with adequate frequency to allow making decisions nearly in real-time. The literature demonstrates that implementation of such monitoring is possible using several data channels, such as manual digital reporting, IoT sensor network, wearable device, equipment telemetry, UAV imagery, and computer vision-based progress recognition. The recent literature emphasizes the maturate nature of sensing and monitoring practices, which enable construction teams to monitor the dynamics of their sites in real-time and consider monitoring as a part of supporting their daily control processes [14]. The other pattern that is consistent is that the monitoring of value is made clearer whenever monitoring outputs are set to operational actions that include those related to daily planning recalibration, safety interventions, quality checks, and validation of progress. It means that real-time monitoring does not represent an independent technology; instead, it needs to be integrated into the process of managing and responsibilities in the case it is to have an impact [15].

The IoT technologies provide a fundamental enabling layer of real-time monitoring since these technologies generate automated data capture, and the human reporting is not fully based. IoT sensors have the ability to deliver real-time flows of data pertaining the location tracking, environmental factors, equipment movements, and safety among the workers, hence, diminishing the aesthetic gaps in information and enhancing the timeliness of reporting. Detailed discussions of IoT sensor technologies highlight the range of sensor possibilities, as well as the application practices of sensors in real construction sites, in the calibration, performance, reliability of the network, and management of non-homogenous data streams [16]. More than fundamental sensing, other studies focus on the concept of the so-called smart construction monitoring systems, including the integration of point cloud data, IoT-

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related data, and platform-provided reporting to develop more closely integrated monitoring environments, which implies more detailed site representation and more data-driven supervision [17]. Nevertheless, the same body of literature alerts that the IoT implementations can easily collapse, when not clearly governed and subjected to operational regularities of sustaining the devices and confirming the quality of the data [18].

Another theme that is closely related is the use of edge computing in real-time monitoring. The construction sites also tend to experience unreliability in connectivity or bandwidth; therefore, some of the situations do not support the monitoring based on the cloud alone [19]. This can be addressed by edge computing, which computes data at the source (e.g., on-site gateways or edge devices) and synchronizes with the cloud systems when there is connectivity and latency is reduced and resiliency is increased. The studies on edge computing to support real-time monitoring in construction hold that edge the integration of edge-cloud is specifically applicable at construction sites where real-time-sensitive each-safety, or each-operations decisions are necessitating low-latency analytics. It is also stated in this view that the real-time is not a binary or a state but a variation of timeliness; that is based on maturity of a network and the structure of data pipeline [20].

UAVs and the monitoring through the drones are also becoming a topic that should be mentioned in relation to the ground-based sensing, in particular, the visual evidences of the progress, safety, and logistics available at the site. According to the literature, UAV imagery may help decrease the use of manual inspection as it is possible to scan the sites frequently and conduct the systematic visual recording that could be used further to rely on analytics or auditing. According to the latest surveys on drones and AIoT-powered UAV surveillance, drones are of importance to the inspection and tracking of progress, but significant limitations to drones include flight restrictions, safety hazards, environmental limitations, and data analysis needs [21]. Systematic reviews on UAV integration to Construction 4.0 also refer to the position of drones as an intermediary between traditional inspection processes and digital monitoring processes, especially in the context of integrating them with digital reporting systems and analytics .Practically, the best application of drone-based monitoring is where embedded into a prescribed governance process like periodic capture of progress, standardized forms of reporting, and accountability of interpreting the results and initiating corrective measures [22].

There is also a considerable amount of attention dedicated to computer vision and deep learning that allows implementing automated interpretation of monitoring data, especially when the monitoring channel is visual. The studies of deep learning-based anomaly detection in structural health monitoring prove that the AI-based technique can adopt the abnormal trends and possible flaws, facilitating the early warning and the prioritized inspection [23]. The same logic is being extended to recognition of construction progress, compliance checking of the all safety, and checking the automation of quality inspections yet the model performance is often inconsistent because of site clutter, light variations, occlusion, and variation of the construction scenes. It is thus understood in the literature that AI-driven monitoring systems are likely to work well under the condition that they are supplemented with well-organized data capture habits and depending on outputs as an aid in the decision-

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making process instead of blind automation [24].

Although it is true that surveillance technologies have been growing tremendously, cloud computing still proves to be an essential facilitator of cross-stakeholder cooperation and centralized information disclosure. The nature of construction projects is to be shared among the organizations, and cloud applications can facilitate the tensions of communicating monitoring results between the clients, consultants, contractors, and regulation bodies. The studies on collaboration in the AEC industry also focus on the idea that cloud computing is capable of enhancing coordination, minimizing information silos, and enhancing project communication in case it is aligned with the project processes [25]. The monitoring literature also demonstrates that cloud-based progress management is most beneficial when project control routine reform together with the cloud considered as a storage facility instead of viewing the cloud as a storage facility [26]. Such results can be straight up applied to real-time observing, as in continuous capturing and no meaningful sharing and interpretation, there is little value. Therefore, cloud systems might be considered components of a unified monitoring workflow system which bridges the gap among the data capture and validation, reporting and decision making [27].

These possibilities have been extended by the advent of cloud-native computing which focuses on scalable, resilient, and modular architectures. Cloud-native systems normally go with the microservice model, containerization, orchestration, and continuous delivery patterns and practices in order to ensure that software systems can scale on command and develop with minimum levels of downtime. This can be especially critical in a monitoring context since real-time systems can have non-constant loads and need quick restarts as monitoring needs can vary amongst projects and between stakeholders [28]. An effort on cloud-native deployment strategies and portability emphasizes how containers and new methods of deployment can enable flexibility and limit the issue of vendor lock-in, which can affect practitioners in risk-averse industries [29]. Studies on next-generation cloud architectures also state that it requires real-time dynamism and responsiveness in distributed infrastructures, which also validates cloud-native concepts to real-time monitoring. However, the adoption of construction can still be based not only on the technical promise of the cloud-native system but on the organizational readiness to make investments in new architectures and the ability to make their usage [30].

Another important area of research is how to connect BIM and digital construction ecosystems. No single standardized strategies of BIM-based monitoring are followed, but essentially, it focuses on connecting evidence of progress and digital models through which it provides more accurate tracking, verification, and reporting. The cloud-based BIM progress management research indicates that the real-time progress can be restructured to enhance reliability of progress control and reporting through the stakeholders. Additionally, the study on BIM–IoT integration points to the opportunity to display real-time sensor data in model-driven visualizations and to aid decision-making by providing more contextualized monitoring results .The research on the topic of BIM and IoT integration to digital twins also indicates that more advanced integration may allow predictive monitoring and scenario analysis, but more data maturity and governance readiness are also needed [31]. Taken together, this body of literature suggests that the most valuable monitoring systems are those

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systems which link sensing and reporting to project information structures, though it would then also suggest that such integration introduces demands on data management and capability requirements which are even higher [32].

The issues of cybersecurity and governance are still a hurdle in cloud based and interconnected construction systems and especially in cases where the monitoring of projects involve sensitive project details, contractual proof and access of multiple organizations information. The area of the research about cybersecurity risks in construction settings states that online systems might make companies more vulnerable when access management and control are not properly implemented [33]. The same thing can be said of identity and access management research which states that secure access control is a bottom-level consideration when it comes to trusting others to share the platform in an organization, particularly when stakeholders are sensitive to boundaries and auditability. The studies on data governance in cloud-based analytics also indicate that these systems need clear policies regarding ownership, access rights, compliance and management of data lifecycle [34]. The integrity and traceability of monitoring records comes under the spotlight of many construction projects where disputes and claims are among the standard fare, hence the mechanisms of governance cannot be introduced as technical add-ons but as mandatories of adoption which determine the credibility of monitoring outputs as evidence by stakeholders [35].

Human and organizational factors are also a major constraint that is evident in a large portion of adoption literature. The failure of digital construction transformation is a common occurrence that is caused by a lack of skills, ineffective training pipeline, change resistance, and disjointed organizational culture [36]. It is evident that the research on digital skills in construction points to a need to have definite skill taxonomies and programmed capacity-building pathways, thus the monitoring of adoption requires workforce readiness and the presence of jobs that can operate this kind of digital system and analyze the results collected by it. The study of the organizational culture also indicates similar results that digital transformation presupposes the management of behavioral resistance and routines redesigning, especially when technologies impose on the long-established reporting practices and supervision practices [37]. Such insights are consistent with views of the theory of adoption that emphasize facilitating circumstances and organizational preparedness on the important determinants of technology adoption, particularly within multi-stakeholder and complex environments. According to the literature, therefore, the best way to consider monitoring adoption is as an organizational change program, which is supported by capability development, as opposed to a technology procurement exercise [36, 37]

Economic and investment considerations also influence the decisions to adopt new technology particularly in developing settings whereby organizations might view the new technology investments as risky or not in line with the short-term demands of the project. Empirical analyses of cloud adoption in construction determine drivers and challenges that entail costs consideration, perceived value, management commitment, and the implementation plan clarity, which means an organization needs evidence of value and a realistic roadmap before increasing adoption [38]. Some research suggests that the money spent on sensors, connectivity, and platform subscriptions should be

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made up for by measurable improvements in the reliability of progress, the quality of documentation, and the efficiency of coordination. This shows that perceived benefits and validity of the proposed implementation plans determine the adoption monitoring. This is the reason why the literature is becoming more supportive of the concept of phased deployment strategies that prove that they have early wins and gradually become more mature in terms of monitoring [39].

The technology adoption theories introduce further framework of interpreting such constraints and opportunities. The adoption model reviews have shown that TAM is still effective in development of perceived usefulness and ease of use, and the condition of construction might demand a broader adoption model since adoption is conditioned by organizational and environmental readiness [40]. The TOE lens states that the adoption of technology has been driven by technological preparedness, organizational strengths, and environmental demands and in this case, it is especially applicable to the construction where stakeholders work under regulatory, customer, and market forces [41]. UTAUT views also put emphasis on the contributions of the social influence as well as enabling conditions which fit best on construction environments where adoption of technologies is influenced by project norms, client needs, and support organizations [42]. Collectively, these frameworks reinforce an opinion that the introduction of cloud-native monitoring in the construction industry should be analyzed in various perspectives instead of a purely technology-based discourse.

In Pakistan and other related settings, studies are increasingly highlighting the need to use a concerted, policy and institutional intervention to help facilitate the process of construction digitalization to break the capability divide and fragmented adoption. The literature on policy interventions on digitalization in the construction sector in Pakistan has concluded that development will occur upon structured drivers, policy stimuli, and focus on intervention as opposed to targeting the experimentation of firms independently [11]. Similar studies on the topic of artificial industry in Pakistan also underline that the lack of preparedness, lack of skills, and institutional coordination are also areas that have to be coped with to bring such advanced digital tools into scale [43]. The insights are especially applicable to the case of Islamabad where the manual and paper-based monitoring practices that persist point to the adoption barrier being more of a governance and capability maturity issue than benefits awareness. Hence, according to the literature, a solution that includes the combination of empirical prioritization of local barriers with the implementation map that superimposes the barriers hindering institutional and organizational activities would be a viable approach to take.

In general, the literature confirms that real-time construction monitoring is technologically viable and can result in tremendous value due to transparency, sufficient quality of documentation, better safety management, and more rapid decision-making when included in project controls practices [44]. It also shows that cloud and cloud-native systems have the potential of facilitating the ability to have scalable multi-stakeholder access, workflow, and dynamically evolve systems, which are becoming significant in situations of real-time monitoring [22]. Nevertheless, its barricade is limited by a multi-layered barrier framework that entails IoT and infrastructure preparedness obstacles, cybersecurity and oversight hazards, digital

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dexterity restrictions, institutional change resistant, and investment risks [45]. These limitations are likely to be further enhanced in the context of the Islamabad construction industry not only by the existing use of traditional monitoring approaches but also by the necessity to coordinate cross-stakeholders. Therefore, the gap identified in the current research could have been the questions:
Is real-time monitoring a useful tool in theory?
Are the barriers and opportunity identified by stakeholders the most critical part to consider in the local adoption and constructing a viable, phased implementation framework based on stakeholder-prioritized interests?

Research Methodology

The research approach included pragmatism orientation research position and applied descriptive-analytical research design as a method of identifying a methodologically defendable study and a direct useable study by the construction stakeholders in Islamabad. Pragmatic orientation fits best in studies of digital adoption due to the fact that the issue at hand is not theoretical but instead one that entails the endeavor of intertwining the technical constraints, organization governance realities and the limitation of human capabilities that cannot be resolved through abstract explanation but instead by taking concrete steps. The research was, therefore, deductive in nature where ideas and factors of adoption of candidates were initially derived based on what is already known and then evaluated and ranked empirically on the basis of primary data. This framework was critical in the sense that it ensured that the proposed implementation framework was based on both the academic evidence base and the local practitioner viewpoint.

The methodological process was applied by way of a flow of interconnected stages that were aimed at transferring the literature evidence into practically context-sensitive priorities and, eventually, a validated implementation roadmap. In the first stage, there was an organized literature review to find the main adoption barriers and enabling factors of cloud-native platforms and real-time construction monitoring. The review methodology also focused on rigor, transparency and controlling the scope of the review which was conducted as per accepted guidelines on systematic literature review methodology so that factors extracted represented credible and recent research as opposed to isolated views [46]. Given the theme of developing-economy backgrounds, the search strategy was introducing peer-reviewed publications and plausible conference publications on cloud-native architecture, IoT-enabled monitoring, construction digital transformation, and integration issues related to technology adoption. Those candidate factors were derived and put into thematic areas that expressed technological readiness, organizational governance, investment constraint, workforce ability, and regulatory uncertainty. This step had two purposes: it delimited the scope of the conceptual understanding of adoptions in the study and it guaranteed that the questions under the questionnaire constituted the entire range of hindrances and opportunities that have been made known in similar building contexts.

The second step made use of an expert-based refinement method in the form of a Delphi in order to enhance contextual relevance. The Delphi methods are very popular in situations where the study needs consensus around expert judgments on a group of variables, especially in complicated areas where the successes of

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implementation to be achieved are case-dependent and depend on the experience held by a practitioner [47]. In the current research, the experiences of experts were sought to select relevance of factors gained through literature, narrow phrasing of items so that the respondents in the Islamic context of Islamabad could understand them, and shorten the item list of factors. This was necessary as cloud-native monitoring is a new concept within the Pakistani construction market and a literature-based tool may contain elements that are either inapplicable within the nation or may as well be interpreted in different ways by the professionals. The purified list was next operationalized into questionnaire statements, which could be gauged by using a standardized response scale.

The third stage was questionnaire development and piloting. The survey tool was designed into two functional sections respondent profiling and adoption-factor assessment. The initial section obtained some background information like organizational type, role in construction projects, professional experience, and educational qualification so that they can be interpreted and grouped as required. The second section consisted of 30 statements pertaining to the adoption with a five-point Likert scale (i.e. strongly disagree, strongly agree, etc.) that allowed quantifying the intensity of the perception consistently and allows ranking as well as inferential testing. It was pilot tested on the questionnaire to confirm that the terms were readable, words were used ambiguously, and respondents of varying IT exposure can still be able to read an item in a similar way. This was exceptionally so since the research is discussing a technology subject which is likely to be seen differently by site-centered employees than employees who are digitally inclined. The improved pilot questionnaire was ready to be distributed in the field after the pilots were improved.

Data collection and sampling was aimed in such a way that it sampled construction professionals who would be in a position to assess extension of adoption feasibility and barrier in the construction ecosystem of Islamabad-Rawalpindi. The sampling strategy was considered as a hybrid approach which merged use of snowball sampling with purposive sampling to determine the relevant respondents and increase the number of the respondents using professional network. The purposive sampling was required to include initial respondents who were directly involved in project monitoring, digital transformation initiatives, or project construction management decision-making, and snowball technology was used to reach more eligible professionals in a specialization domain in which a comprehensive sampling frame is challenging to form. The sample size that needed to be used in the study was informed by the principles of Cochran of the determination of a sample size, the required sample size needed to provide a good representativeness at 95 percent confidence level with a 5 percent margin of error considering the number of persons in the construction industry that constitute the active population of the region. It was a way of obtaining a final dataset to be descriptively profiled, stakeholder perception ranking and comparison in groups.

The collection of the data was carried out by distributing 105 questionnaires to the professionals who were involved in the construction planning, execution, management, and monitoring in the city of Islamabad. The screening of responses proceeded to ensure that the responses were complete and aligned with the eligibility

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profile; responses that were not complete and suitable were eliminated before analysis to safeguard the quality of data. The last dataset included 81 valid responses. The data was first cleaned before coding in order to facilitate the quantitative analysis such as checking of the range of responses, identification of inconsistent patterns, and also preparing a set of categorical variables for testing through group comparison. Such data preparation was important as it made sure that later reliability and inferential findings were based on authentic patterns of perception and not due to the missing or inconsistent entries.

Analysis was done on entrepreneurs involving use of IBM SPSS Statistics by adhering to the normal applied research practices regarding survey based research works [48]. The workflow of the analysis was organized in a way that achieved four objectives that included: (i) characterize profile or baseline perception patterns among the respondents, (ii) test reliability, (iii) identify the right inference techniques that depend on the data distribution and (iv) generate a decision-oriented factor prioritization output that could directly inform the framework development. The respondents were profiled in terms of descriptive statistics and summarized the central tendency and variability of each statement of adoption. Mean values and standard deviations have been calculated to be in a position to get a rough idea of which benefits and barriers were perceived as being strongly felt and which were more unstable or disputed.

Reliability test was undertaken to ensure that the questionnaire questions were able to measure constructs covering adoption in a consistent manner. Consistency was analyzed with the help of Cronbach's Alpha that is a traditional measure of reliability of Likert-type survey tools in practice. The reliability of the scale was measured at the instrument level and the dimension based on the concept designed to determine that the scale was acceptable across various dimensions of factors. In as much as Cronbach Alpha is commonly implemented as a benchmark, studies too acknowledge that it is limited when it comes to the characteristics of the items and base assumptions; thus, alpha interpretation was implemented with reservations bearing in mind the recommended alpha values as well as scale structure [49]. Confirmation of reliability was considered a precondition prior to going to ranking and group comparisons since lacks credibility to unreliable measurement. Normal test was then applied in order to establish whether parametric assumptions could be considered in further analysis. Shapiro Wilk test was employed as distributional diagnostic test since it is normally applied in applied research to verify whether variables are significantly different when compared to normality [50]. The test scores showed the non-normal distribution of response of key items, but it is normal when using Likert scale data of perception outcome because responses tend to be concentrated to either agreement or disagreement side. Since non-normality decreases the suitability of the parametric group-comparison procedures, the research employed the use of non-parametric procedures in testing inferential statistics where the group differences were observed. In particular, the Kruskal Wallis H test was applied to determine whether there were statistically significant group differences between members of the respondent groups (including experience categories, types of organizations, and roles) in their attitudes to adoption difficulties. Kruskal Wallis test is generally accepted to be applicable in the comparisons of independent groups in the case of ordinal

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measurement and non-normal distribution conditions [51]. This enabled the study to determine how some of these barriers like trust in automated outputs or security issues differed in the context of different stakeholder profiles hence enhancing the application of interventions suggested to be applied. In order to come up with actionable priorities, Relative Importance Index (RII) was used on the 30 adoption statements. RII is also very common in construction management research to rank factors given based on perceived importance to stakeholders since it transforms the Likert-scale answers to normalized index where they can be directly compared across a set of items. The index has been calculated by the conventional formula of $\Sigma W/(A \times N)$, where W represents the weight assigned by respondents on a five-point Likert scale, A denotes the highest possible weight (5), and N indicates the total number of respondents. The obtained values of RII (limited to the range of 0 to 1) were used to prioritize the opportunities and barriers of adoption in their order of priority. Such a ranking method fulfilled two important purposes, namely generating an intensifiable set of partially rational decision-making factors, as well as generating the material base of empowering the mapping of stakeholder perceptions into framework actions instead of utilizing standard prescriptions of digital transformation. The last methodological step was the framework development, which was considered an evidence translation process instead of a conceptual exercise on its own. The map was created based on the top-ranked RII factors into implementation action and the arrangement of the action into four dimensions of readiness, including technological and infrastructure readiness, financial and investment readiness, human resource and capability readiness, and organizational and governance readiness. These aspects imply the fact that the presence of cloud-native monitoring is a pattern that requires an ensemble of enabling conditions instead of the implementation of isolated tools. The framework was then laid out as a staged guideline comprising of readiness assessment, system planning and design, pilot deployment and change management and scale-up and optimization. This staged design was chosen because it decreases the risk of implementation and also enables the stakeholders to realize early value prior to increasing the technical footprint of the monitoring systems. Lastly, triangulation of the proposed framework against literature expectations and expert feedback was conducted to ensure the suggested actions were possible in the institutional/industrial environment of Islamabad and engaged with the interests ranked among the high priorities by the stakeholders. To recap it all, the methodology entailed, systematic evidence synthesis, refinement based on expertise and statistical prioritization through surveys to come up with an empirically based implementation framework in implementing cloud-native real-time monitoring adoption in Islamabad. The study combined the reliability testing, distribution diagnostics, non-parametric group comparison, and the RII ranking into one analysis pipeline and made sure the results of this study are not only statistically credible but also could be directly applied to policy, governance, and planning of adopted to the organization.

Results and Analysis

Sample Size and Response Characteristics

Questionnaires were distributed to 105 construction professionals working on different projects in Islamabad. 85 filled in questionnaires were returned and the

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response rate was 80.95, above the threshold that is considered as strong in the case of construction management questionnaire studies. After verifying the data and checking the completeness of the data, 81 of the responses were retained to be analyzed and four were discarded as the data lacked entries or they were not always consistent. The 81 cases of the final sample were deemed to be appropriate in further reliability evaluation, prioritization analysis, and non-parametric group tests involving standard survey analysis processes in SPSS [52]. The demographic profiling shows that the respondents are well-qualified professionals. Regarding educational level among the respondents, 50.6% were with Bachelors, 46.9% with Master and 2.5% had PhD, indicating high level of technical and managerial proficiency to assess the technology based construction monitoring practices. Its spread across organization type also suggests that the data reflects the views of the key stakeholder groups functioning within the context of the process of monitoring and reporting clients (43.2%), contractors (33.3%), and consultants (23.5%), which allows one to interpret the perceptions of adoption in a multi-stakeholder decision-making context common to construction projects. There was a normal outlay of the level of professional experience among the respondents. Individuals possessing less than 5 years of experience made 40.7%, individuals possessing 5-10 years' experience were 17.3%, and those with more than 10-15 years' experience were 22.2% (15-20 years: 11.1% & above 20 years: 11.1%). This dispersion among types of experience is useful to the research of adoption since levels of perceptions of the governance risk, system trust, and constraints on readiness can be often different in early-career and senior professionals. Moreover, the role distribution demonstrates both the operational and decision-making roles representation, though the biggest role groups are the Site Engineers (27.2%), the Project Managers (22.2%), and the Executive Management (18.5%). This combination increases interpretability of results since it involves personnel who are directly involved with site-level monitoring restrictions coupled with managers who are responsible for policy, investments and decision making.

Reliability Analysis

Internal consistency was assessed on pre-factor prioritization and group comparison by evaluating by the use of Cronbach Alpha before the factor prioritization and group comparison which is a common item in practical survey research to determine whether items of a construct are measured on a constant basis [49]. The larger factor groupings were computed and the overall instrument were computed with reliability and yields the result of acceptable-excellent internal consistency. Since Alpha has had acknowledged flaws in their reliance to scale assumptions, interpretation was considered a quality check or on its own validation of measurement quality was not undertaken. The reliability analysis results reported in table 4.1 reveal that there is strong internal consistency of overall instrument.

Table 4.1: Reliability Statistics

Construct	Number of Items	Cronbach's Alpha	Interpretation
Technical Factors	8	0.861	Good

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Organizational Factors	10	0.884	Excellent
Economic Factors	6	0.821	Good
Legal & Regulatory Factors	6	0.798	Acceptable
Overall Adoption Factors	**30**	**0.891**	**Excellent**

Such reliability results justify any form of ranking and inferential analysis as they show consistency in responding to the instrument**.**

Normality Assessment and Implications for Statistical Testing

To establish the level of appropriateness of parametric assumptions, ShapiroWilk test was employed to test the characteristics of distribution of selected variables. The outputs showed non-normality distribution which is typical of Likert-scale perception data. This resulted in the choice of non-parametric techniques to compare groups where the conditions were ordinal/non-normal to accept statistically appropriate implications.

Table 4.2: Normality Test Results for Selected Adoption Factors

Adoption factor (selected)	Shapiro–Wilk statistic	p-value	Distribution
Real-time monitoring improves transparency	0.729	<0.001	Non-normal
Lack of organizational policies slows adoption	0.772	<0.001	Non-normal
Lack of trained personnel limits adoption	0.800	<0.001	Non-normal
Data hacking/loss risk in cloud platforms	0.884	<0.001	Non-normal
Low trust in automated system outputs	0.890	<0.001	Non-normal

As this is the case in this pattern of distribution, the Kruskal Wallis H test was used to study stakeholder and demographical differences.

Descriptive Statistics

All the adoption statements were calculated to obtain descriptive statistics (mean, and standard) in order to determine the baseline patterns of perception. The outcomes reveal that there are high levels of consent with statements that describe benefits especially the improved transparency and reporting quality, where the stakeholders determine that there is significant visible value in the practical implementation of cloud-based real-time monitoring systems. Such descriptive trends also offer a background as to interpreting the ranking results due to the fact that the usefulness is not a barrier as to why it is not adopted as it is more of a readiness barrier which

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prevents adoption.

Ranking of Adoption Factors Using Relative Importance Index (RII)

The Relative Importance Index (RII) was computed on each statement of adoption to transform the perceptions of the stakeholders into decision-focused priorities of the statements. RII is popular in the management research of construction to prioritise barriers and drivers since it standardises Likert-scale responses to the similar importance scores of several factors [53]. Viewing the ranking outcomes, one can also find a specific tendency: the respondents see strong value (e.g., transparency and reporting improvements), and the most binding restrictions have issues with governance preparedness (policies, guidelines), human capability (trained personnel, training), and prepared infrastructure (IoT readiness). The Top 10 factors in the ranking presented in table 4.3 illustrate a very interesting trend: stakeholders regard the governance and performance benefits of cloud-native monitoring (transparency, accelerated delivery, reporting) as of great importance, but they believe there is a significant limitation in the adoption process caused mostly by the policy readiness, human ability, and IoT/technical enabling infrastructure.

Table 4.3: Top 10 Adoption Factors by RII

Rank	Adoption factor (short title)	RII
1	Real-time monitoring improves transparency	0.879
2	Lack of organizational policies slows adoption	0.852
3	Lack of trained personnel limits adoption	0.840
4	Cloud-native accelerates construction activities	0.837
5	Better documentation and reporting via cloud	0.832
6	Lack of IoT sensors limits real-time data	0.827
7	Inadequate training reduces effective utilization	0.822
8	Lack of standard guidelines limits adoption	0.820
9	No clear digital transformation strategy	0.817
10	Sustainability improvement through digital platforms	0.815

To confirm transparency of results, the full ranking for all factors is provided below in table 4.4.

Table 4.4: Top 10 Adoption Factors by RII

Rank	Factor	Mean	RII
1	Real-time monitoring improves transparency between contractors and clients.	4.40	0.879
2	Lack of organizational policies supports slow adoption of cloud-native platforms.	4.26	0.852
3	There is a lack of trained people who know how to use and manage these new technologies.	4.20	0.840
4	Cloud-native solutions can accelerate construction	4.19	0.837

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Rank	Factor	Mean	RII
	activities and project delivery.		
5	Cloud platforms enable better documentation and reporting of construction activities.	4.16	0.832
6	Construction sites lack adequate IoT sensors and hardware to support real-time data collection.	4.14	0.827
7	Inadequate training programs reduce effective utilization of cloud-based systems.	4.11	0.822
8	Lack of standard guidelines for digital construction monitoring limits adoption.	4.10	0.820
9	Absence of a clear digital transformation strategy limits cloud-native platform adoption.	4.09	0.817
10	These platforms improve environmental sustainability by reducing waste and inefficiencies.	4.07	0.815
11	Limited awareness of cloud-native technologies among construction professionals.	4.07	0.815
12	Employees prefer traditional construction methods over adopting new digital technologies.	4.06	0.812
13	Poor coordination between IT teams and project teams affects system implementation.	3.98	0.795
14	Poor or no internet connection on our construction sites stops digital tools from working.	3.96	0.793
15	Budget constraints limit the ability to invest in cloud-native platforms.	3.91	0.783
16	Lack of top management support slows down digital technology adoption.	3.90	0.780
17	Resistance to organizational change discourages the adoption of new technologies.	3.88	0.776
18	Integration of cloud-native platforms with existing systems is difficult.	3.85	0.770
19	Unclear data ownership and governance policies affect cloud adoption decisions.	3.84	0.768
20	High initial investment costs are a major barrier to adopting cloud-native platforms.	3.83	0.765
21	Legal and regulatory uncertainties discourage cloud-based data storage and processing.	3.81	0.763
22	Additional costs for training and system customization limit adoption.	3.79	0.758
23	Costs related to data storage and real-time data processing are high.	3.77	0.753
24	Uncertainty about return on investment (ROI) discourages	3.74	0.748

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Rank	Factor	Mean	RII
	adoption of cloud-native platforms.		
25	Using new digital tools often disrupts our normal work routines and creates extra steps.	3.72	0.743
26	Fluctuations in project budgets make it difficult to sustain digital investments.	3.70	0.741
27	Setting up new monitoring software (like sensors or cloud platforms) is too complicated and time-consuming.	3.63	0.726
28	Site workers and managers do not fully trust the information or alerts from automated systems.	3.51	0.701
29	The benefits of digital monitoring are not reflected in our project goals or performance bonuses.	3.44	0.689
30	There is a risk of project data being hacked or lost when we use online (cloud) platforms.	3.36	0.672

Group Differences in Adoption Perceptions (Kruskal–Wallis)

Since the data could not fulfil the conditions of normality, the Kruskal-Wallis tests were applied to investigate the results on whether there is a difference in perception among demographic groupings. The outcomes suggest that the differences based on experience level are statistically significant on perceptions related to security/trust whereas the differences based on organization type were not significant when it comes to the benefit that comes first in the rank and the barrier that comes first in the rank. Kruskal-Wallis can be fitted with this objective since it compares independent groups as ordinal measured or non-normally distributed samples [54].

Table 4.5: Kruskal–Wallis Test Results for Differences in Adoption Factors across Demographic Groups

Grouping Variable	Adoption Factor	Kruskal Wallis	p-value	Significance
Experience Level	Data security risk in cloud platforms	11.09	0.026	Significant
Experience Level	Trust in automated monitoring outputs	12.18	0.016	Significant
Organization Type	Real-time monitoring improves transparency	0.03	0.985	Not Significant
Organization Type	Lack of organizational policies	1.14	0.565	Not Significant

These results imply that while risk perceptions regarding automation and security are more responsive to professional experience, governance and transparency are widely acknowledged priority across stakeholder groups. This distinction is crucial for implementation planning because it shows that although security and trust require

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focused assurance and training initiatives to foster confidence across experience levels, governance improvements may be pursued as shared goals.

Framework for Implementation of Cloud Native Platforms

The structure in the figure 4.1 offers a direct challenge-response route for deploying cloud-native real-time monitoring in Islamabad, based on the most important adoption limitations and advantages. The framework assigns a leadership role to Pakistan Engineering Council (PEC) due to the absence of organizational policies i.e. suggesting uniform guidelines on cloud-based construction monitoring, but at the same time demands construction companies to formalize internal cloud adoption and data governance policies, yet the Capital Development Authority (CDA) is the investee to reinforce by appreciating digital monitoring compliance during all project approvals and inspections. To mitigate the lack of a digital transformation strategy, the framework suggests a logical Digital Transformation Roadmap of the significant projects of Islamabad and makes clients (public and private) insist on the popularization of digital monitoring plans at the beginning of the project to ensure that the implementation of the work occurs throughout. The absence of standard digital monitoring practices is managed by collaborative standard-setting in which PEC and CDA lay down the minimum standards of dashboards, reporting formats, data updating frequency and system functionality in addition to promoting approved and interoperable platforms in which uniform progress tracking and documentation reporting may be attained. The weaknesses of human capabilities are included by two complementary interventions: where un-trained personnel are involved, the structure suggests that cloud-native monitoring modules are introduced in Continuing Professional Development (CPD) courses of PEC and compel companies to bring digitally-trained site engineers to projects in Islamabad; in case of insufficient training programs, the frame gives the superior authority to the Higher Education Commission (HEC) by proposing cloud-based monitoring laboratories on Islamabad university campuses and a mandatory on-site digital training before mobilization. The non-availability of IoT sensors and hardware is addressed by technological readiness by countering with the deployment of sensors in stages, the continuity of the network of portable 4G/5G sensors, and edge-cloud integration in maintaining continuity of monitoring in varying site network densities. Performance-wise, the framework aims at preventing low transparency and associated delivery inefficiency by implementing cloud-based project management portals, shared stakeholder dashboards, and centralized information sharing to minimize conflict and accelerate decision-making, as well as weak documentation and reporting by converting paper-based records to cloud documentation systems and persuading CDA/client accepting digital records to conduct audits and approvals. Lastly, the framework includes environmental sustainability as it suggests cloud-based monitoring of material usage, wastage, and rework and alignment of sustainability reporting with the requirements of Pakistan Environmental Protection Agency (Pak-EPA) to enhance the level of regulatory compliance and accountability.

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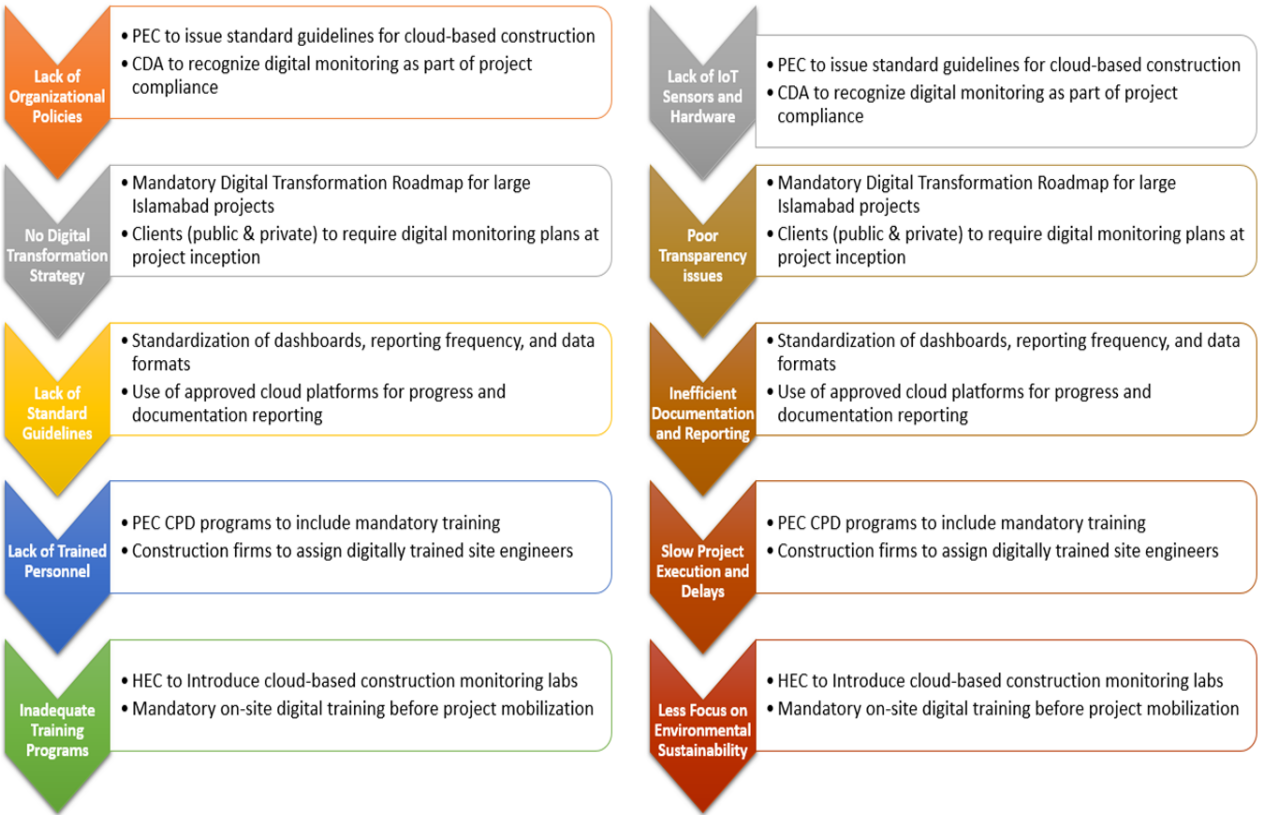
Figure 4.1: Framework for implementation of cloud native platforms



Conclusion and Recommendations

Conclusion

This paper explored implementation of cloud-native platforms on real-time construction monitoring in Islamabad by determining those perceived drivers and barriers by stakeholders and converting the most critical ones into an implementation framework. The evidence of practices shows that the experts working in a construction industry of Islamabad pre-eminently perceive the value case of real-time monitoring, especially in enhancing transparency among participants, enhancing the quality of documentation and reporting process, and aiding quicker decision-making throughout the project implementation. These benefits as perceived are significant since they solve the numerous challenges in governance in the construction delivery process particularly information delays, fragmented coordination and limited traceability of tasks with monitoring practices generally being unreactive but reactive.

Simultaneously, the analysis indicates that adoption is majorly limited by the readiness constraints which can be both the organizational and the capability-based ones as opposed to the merely technological constraints. The first-order barriers are the unavailability of organizational policies, unavailable guidelines of standard checking digital observance, absence of trained staff, and insufficiency of training processes implying that implementation needs organized control and building of human capabilities to be cost-effective outside of single flyers. Moreover, the

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infrastructure limitations especially facilitate IoT sensors, and unreliable connectivity make the real-time data capture at scale less feasible in practice, which underlines the importance of the phased roll-out approaches reflecting the conditions of a site and its maturity.

These realities are addressed in the proposed framework via a logical, systematic challenge-response that explains the responsibilities of institutions (PEC, CDA, HEC, and Pak-EPA) and coordinates the implementation of action at the project level and prioritization of actions according to the rankings of the stakeholders. The standardization of governance, ability to develop the workforce, and facilitate the gradual enhancement of infrastructure as central adoption conditions is aimed at enabling the workforce to help institutionalize cloud-native monitoring in the construction industry of Islamabad but also help to facilitate transparency, performance management, and sustainability accountability. In general, the research is relevant to the context specific empirical analysis and implementation recommendation on the development of real-time monitoring adoption in the construction industry of Pakistan where the mismatch between the complexity of the projects and the level of monitoring is one of the main limitations.

Recommendations

In order to operationalize the adoption of cloud-native real-time monitoring in Islamabad, institutional, organizational, and project execution levels of the recommendations have been made. To start with, standardization of governance should be considered as a preliminary event and not as late stage activity. Standardized guidelines that specify minimum digital monitoring capacity (dashboards, frequency of reporting, data formats, evidence standards, etc.), should be issued by the Pakistan Engineering Council (PEC), and digital monitoring compliance formally regarded in the Capital Development Authority (CDA) project-approval and inspection regulations to establish enforceable market demands to use them. Digital monitoring plans should be mandated by both state and non-state clients at the start of the project and entrenched in tender and contract documentation so that it is not a choice to embrace.

Second, the ability of workers will have to be reinforced by intelligent professional and academic training routes. PEC CPD initiatives must include compulsory courses related to cloud-based monitoring processes and the actual use of the platform, and to ensure underutilization is minimized, construction companies ought to employ digitally educated site engineers to work on the projects to enhance monitoring routine persistence. Concurrently, Higher Education Commission (HEC) ought to encourage construction monitoring laboratories which are cloud based in universities and promote systematic training programs before mobilization of projects to ensure that graduates come out of universities with relevant monitoring skills.

Third, it must be implemented in a staged technology approach that is in line with site preparedness. To achieve a baseline level of transparency and documentation benefits first and foremost, projects must first focus on standardized cloud reporting, shared dashboards, and a centralized repository of documentation, and gradually consider the possibility of integrating IoT sensors and other hardware where the connectivity and maintenance are guaranteed. Lastly, the outcomes of sustainability must be

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institutionalized in that the material use, waste and rework materials should be irrigated through cloud records and the reporting practice needs to be suitable to that of Pak-EPA so that accountability could be measured instead of informal sustainability statement. All these measures facilitate scalability, as they address both governance needs, capability needs, infrastructure needs and sustainability needs in a sequential roadmap aligned to the stakeholder-ranked priorities.

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