CHAPTER 42

Improving Formwork Deployment Efficiency through Workforce Skill Gap Analysis and Targeted Training Models

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ABSTRACT

Improving manufacturing productivity while ensuring safety and quality practices requires reliable, data-driven methods for measuring employee performance and optimizing formwork operations. Recent advances in artificial intelligence, online training, and automation offer strong alternatives to traditional experience-based and manual methods. AI based motion recognition using video data allows for precise measurement of individual worker activities and identification of inefficient actions in column formwork operations. This supports targeted training and performance improvement. Online upskilling programs have significantly increased productivity, especially among mid-career employees and in technically demanding trades like shuttering carpentry. Formwork deployment optimization models that consider construction schedules, concrete strength gain, formwork reuse cycles, and time related costs clearly show the significant impact of time on overall formwork economy. Emerging technologies, such as BIM-based formwork planning, multi-criteria decision-making models for formwork system selection, and 3D point cloud-based inspection frameworks, further enable data-driven planning, automated quality control, and better coordination among project stakeholders. Current digital formwork management faces challenges like project scale, data availability, and local constraints. Existing research shows that AI-driven productivity analysis and BIM-based planning models enhance production efficiency and cost management.

Keywords: Artificial Intelligence (AI), Formwork Optimization, Productivity Analysis, BIM Based Planning, Digital Upskilling.

1.0 Introduction

Operation of formwork work is at the core of reinforced concrete building operations, as it has a direct influence on the security of reinforced concrete structures, surface finish,

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DOI: 10.17492/JPI/NICMAR/260542 ISBN: 978-93-49790-68-1

rate of building operations, cost efficiency, among others[1]. Despite the vast advancement in relation to reinforced concrete building operation systems, such as modular systems, climbing systems, system formwork operations, the execution of operations in the actual building sites is deeply dependent upon manpower skills[2]. Most building operations, especially in a developing economy, have a majority of semi-skilled manpower or even some who have no formal training in relation to building operations but rather focus mainly on experience gained from actual operations.

Skilled labor shortage has become an acute problem in the construction industry worldwide, further exacerbated by rapid infrastructure growth, urbanization, and the increasing complication of construction technologies[3]. Usually, contractors rush into deploying large workforces with little time for structured skill assessment or training. In the formwork operation where accuracy, sequencing, and safety compliance are of critical concern, such skill mismatch can produce cascading impacts on project outcomes. Many recent literatures recognize the facts that improving formwork performance is not only a matter of selecting the right system but also ensuring that the workforce deploying it possesses the required competencies.

This review paper critically reviews the existing literature on workforce skill gaps, productivity assessment, training methodologies, and digital interventions related to formwork deployment. Such a review synthesizes findings from construction management, workforce development, automation, and training assessment literature with a view to establishing a structured understanding of the critical formwork skills, existing gaps, and effective training models[4]. The aim is to develop a sound theoretical basis for the analysis of workforce skill gaps and for the proposition of a structured training model tailored for formwork deployment.

2.0 Importance of Formwork Operations in Construction Projects

It can be noted that the operations related to the use of the formwork in the construction of reinforced concrete are of great importance, as these include factors related to the structural integrity of the structure, durability, safety, costs, and speed of construction of the structure in question. It can also be noted that the use of the formwork in the structure, which can be said to be of a temporary nature, plays a critical role in influencing the quality of the concrete structure in terms of geometry, dimensional precision.

From a cost perspective, formwork represents a significant portion of total reinforced concrete structural frame costs, ranging from 25% to 60% in total cost[5]. The total cost includes not just direct material costs but also includes the associated cost of labor with respect to assembly, adjustments, dismantling, and maintaining an erected formwork system.

DOI: 10.17492/JPI/NICMAR/260542 ISBN: 978-93-49790-68-1

Hence, even small improvements in formwork can lead to considerable cost benefits in terms of cost reduction.

The use of formwork can also directly influence the construction cycles of the building, particularly for multi-story constructions, as well as engineering projects in general. The operation of laying slabs, casting the concrete for the walls, among others, can all be affected in terms of how the construction cycle will take place, thus the need for careful considerations in the use of the relevant formwork technology in the process[6].

Safety is a significant issue in respect to formwork activities due to the fact that formwork systems provide a system that acts temporarily to support loads such as freshly molded concrete materials, construction loads, and winds or dynamic effects resulting from the construction process itself. Thus, catastrophes resulting from poor configurations or premature stripping may cause serious accidents, fatalities, or consequences in terms of litigations or financial damages to those involved in construction processes; thus, formwork is consistently recognized as a high-risk process in construction activities itself[4].

Similarly, results obtained for quality aspects in concrete construction can entirely depend upon the workmanship achieved for formwork used in concrete construction. Dimensional acceptability, alignment, plumbness, surface finish, as well as sharpness of edges, are all functions of the accuracy of formwork arrangement[6]. This can lead to defects in workmanship in terms of features like honeycombing, bulging, and misalignment.

In spite of the improvement in the technology for formwork systems, such as modular systems, aluminum systems, table systems, and climbing systems, the literature points out that the success of these advanced technologies is largely based on the efficiency and skill level of the workforce. Essentially, the advanced technologies in these systems would result in higher efficiency and safety only if the workers are trained sufficiently to use the right techniques for assembling the systems.

3.0 Workforce Skill Gap in the Construction Industry

3.1 Concept of skill gap in construction

The workforce skill gap within the context of construction refers to an observable difference between what skills are needed on-site to enable an effective performance of activities within the field and what skills are made available through workers. In contrast to manufacturing, whose skill development processes are standardized, the construction industry exhibits an informal or fragmented environment, meaning any skills developed are experiential[3]. This defines and explains the structural setting to which strong skill gaps are attributed.

DOI: 10.17492/JPI/NICMAR/260542 *ISBN: 978-93-49790-68-1*

In form work, the specific skills required during form work activities also identify these gaps as particularly pertinent, considering form work is essentially a temporary and a load-carrying activity. Skill gaps also go beyond mere manual proficiency and include skills such as theoretical knowledge, decision-making, and coordination[3]. An individual, for instance, may know how to assemble things but may not fully comprehend the engineering and the sequence of activities involved.

The literature identifies two types of skill gaps: perceived and actual skill gaps. Perceived skill gap happens if supervisors rely on experience to assume employees' skills, whereas an actual skill gap can be determined through an assessment of an employee's performance.

3.2 Causes of skill gaps in formwork deployment

Several are the reasons for the skills gap related to the deployment of formwork identified and traced by literature, and the most significant of them include the informal character of the training processes. Normally, skills are developed and acquired based on observation and repetition of operations, and the worker is never exposed to the underlying principles and theories that inform the operations that are being executed[3].

Yet another major contributing factor revolves around the rapid evolution in formwork technology. This revolution in changing conventional timber systems to modular steel sections, aluminum formwork systems, table formwork systems, and climbing system formwork has impacted skill levels considerably. Here again, a consistent finding in literature has been that if technology is upgraded without upgrading the workforce skill levels accordingly, the problem ends up being aggravated instead of being solved. Labor mobility further exacerbates this. Workers in the construction industry move frequently from contractor to contractor and from project to project, discouraging continuity in skill-building. Contractors are usually hesitant to invest in the training of workers who might not be in the organization for long. This leads to systemic underinvestment in skill-building at the industry level. But the language barriers, low literacy levels, and cultural differences-let alone a lot of migrant labor-further limit the effective application of conventional training methods. Written manuals and oral instructions may not be well comprehended, with learning by trial-and-error becoming the norm. These learning approaches are quite dangerous for high-risk activities like erecting and dismantling formwork.

4.0 Critical Skills Required for Formwork Deployment

The deployment and placing of formworks are highly skill-intensive jobs that require an understanding of structures, manual skills, safety awareness, and productive skills

DOI: 10.17492/JPI/NICMAR/260542 ISBN: 978-93-49790-68-1

management[7]. Unlike other trades, if formwork operations are incorrectly performed, defects are not localized; instead, defects will grow in different ways in structural safety and productivity problems. The literature highlights that skills required in formworks are understood as a multi-layered competency model rather than simple physical skills tools[7].

4.1 Technical skills (system-wise perspective)

4.1.1 Conventional formwork systems

The nature of skill requirements in conventional timber or plywood-based systems is mostly craft-based in terms of measuring, cutting, assembling, and bracing in place. This implies a strong foundation in geometry and tolerances in dimension making and cutting. For instance, inaccuracy in cutting lengths or nailing can impact the structural stiffness and load-resistance capacities of structures. The literature shows that in traditional systems of construction using forms, individual craftsmanship is a major aspect where differences in skill are a major source of variability in quality and safety in structure work[1].

Another significant technical knowledge gap relates to knowledge of load transfer mechanisms. The workers need to have knowledge of the mechanisms by which fresh poured concrete transmits its weight to the sheathing, studs, walers, or props, which are embedded in the earth or connected to it. Indeed, many workers construct the formwork based on intuitive cues rather than design considerations[1]. This is a common thread running through many reported cases of faulty execution in relation to formwork.

4.1.2 Modular and system formwork

With the move towards modular steel and aluminum formwork systems, the nature of technical skills itself has shifted. These are designed as engineered items with a capacity and a number of cycles of use. Henceforth, there is a need to adhere strictly to the manufacturer's information.

The workers need to recognize components in a system and understand the rules of standard connection logic while also being able to assemble components in a particular order as specified in a standard connection logic chart or a flowchart[2]. There are also chances for misplaced pins and incorrectly tightened connectors or replacing components incorrectly—all because of workers applying their own non-standard connection logic to a standard module-based connection logic and thus impacting its associated advantage in favor of improved performance[2]. Furthermore, a precise alignment of these systems is essential during the construction of modular schemes. If misaligned, these structures may cause problems when their number is large since a tiny error may cause problems in the aspect of verticality, as well as levels of the floors.

DOI: 10.17492/JPI/NICMAR/260542 ISBN: 978-93-49790-68-1

4.1.3 Climbing and advanced formwork systems

At its highest level of technical complexity, climbing and self-climbing formwork systems act as a singular unit to incorporate formwork systems, working platforms, anchorage systems, and systems for lifting or using hydraulics[2]. At this level or stage, technical competencies not only incorporate systems assembly but also cover system behavior or response during climbing and bearing loads from partially cured concrete.

The workforce also needs to be adequately trained in the proper sequence of the operation process, ranging from the installation of the anchorages, the release mechanism, and the climbing of the equipment itself, as a mistake in any of the processes can lead to a catastrophic outcome[2]. The relevant literature also highlights the need to understand the importance of the potential occurrence of accidents in climbing equipment, the main reasons for which include human failures resulting from inadequate training of the workforces in the sequences of operation of the equipment itself.

4.2 Safety skills: Collapse mechanisms and human error pathways

The safety skills in formwork operations are an integral part of technical competency and possess specific cognitive and behavioral skills. The mechanisms in formwork collapse, as noted in the literature, are a combination of design, construction, and unsafe practice factors. Human factors are a dominant source in most cases[3].

They must also be familiar with common failure modes such as blowouts from excessive lateral pressure, progressive collapse from inadequate bracing, as well as failure from premature stripping of jacket pipes. If workers are unaware of these parameters, they may be unaware of associated risks in relation to increased rates of concreting, improper application of vibrations, and changing paths of loading.

There is also a possibility of human error, and such circumstances occur via a path known as Normalization of Deviation, when operators undertake dangerous work processes as a result of production pressures[5].

4.3 Productivity skills: Crew coordination and cycle-time control

Productivity in the operations involving forms also extends beyond personal speed. Literature mentions the following: Productivity of work carried out during the formwork period is related to task integration and division of labour[5].

For skilled crews, there is an evident ability to balance parallel and sequential activities so that there is minimal idling and minimal amount of going back and forth. For instance, skilled crews are able to appropriately link activities related to the panel assembly and the incorporation of reinforcements in a manner that these activities do not hinder one another. Badly skilled crews operate in a reactive manner[5].

DOI: 10.17492/JPI/NICMAR/260542 ISBN: 978-93-49790-68-1

For examples of processes that require attention to cycle time control, consider a slab casting process for a new high-rise building. Small efficiencies that are lost in a cycle can add up to serious overrunning of a project. Productivity skills therefore include a capacity for planning foresight, communication skills, as well as flexible adaptability to new situations. These are generally lacking in most training curricula.

5.0 Critical Review of Traditional Training Models

Being classical, the models of training adopted in the construction industry, particularly in formwork operations, have, in fact, proven largely incompatible with modern formwork operations, which was largely a non-engineered item, using timber sections, tolerances, and largely using rule-of thumb methods, which through oral, experiential methods of training were judged adequate, largely due to the forgiving nature of such systems and the safety conditions being low in consequence[7].

On the other hand, modern systems consist of a constructed assembly with engineering capacities, connection and anchorage logic, and precise sequencing requirements. The formation and effective usage of modern systems depend not only on proper assembly but also require an understanding and interpretation of interacting factors, including concrete pressure, pouring rate, and curing/support reactions[7]. Hence, training based on exposures alone is not effective anymore.

The literature has identified that traditional training is not failing incrementally but is a structural phenomenon built upon an underlying notion that assumes certain types of skill automatically develop through individual experiences. This notion is not valid in operations involving formwork because of failures in informal learning and an interpretation of experience, coupled with an erosion of skills because of pressure in project operations.

5.1 Failure of informal learning in formwork operations

Informal learning dominates construction because it is fast, inexpensive, and embedded in daily work. Workers observe others, imitate the actions, and repeat them until the tasks seem to get the job done[1]. This model works only when cause and effect are directly visible. In formwork operations, this condition does not exist.

The most critical aspects of formwork behavior-lateral concrete pressure buildup, redistribution of loads through walers and ties, progressive loss of stability, and interaction with partially cured concrete-are not visible during execution[2]. A wall form may look stable moments before collapse. A slab may appear adequately supported until stripping initiates redistribution failure. As a result, workers cannot visually associate incorrect actions with delayed consequences.

DOI: 10.17492/JPI/NICMAR/260542 *ISBN: 978-93-49790-68-1*

This creates a perilous learning gap. Informal learning conveys procedures without principles. Workers pick up what to do-place a prop, pull the tie tight-but not why it must be done in a certain configuration. Without principles, workers can't adjust when circumstances change. Suddenly increasing the pour height, using a faster pour rate, changing the geometry, or substituting systems nullifies what has been learned.

5.2 Why experience does not translate to competence

Experience can be considered a substitute for competence in the construction industry because it can be easily gauged in society. However, the research suggests that experience only reveals being exposed but not understanding the subject matter.

For operations performed in formwork works, experience can mean doing the same tasks over and over in a similar setting without a real evaluation process[3]. The worker may claim to have "10 years of experience in assembling formwork," but he could never really encounter critical variations in terms of pressure from concrete, types of anchorage systems, or even climbing operations during work. Experience, in this regard, is bounded and nontransferable.

In contrast, competence requires mental models that are generalizable, i.e., the capability of predicting systems' behavior in novel conditions. Experienced workers are unlikely to have a conception of the systems' behavior, and instead, their responses are grounded on intuition that was formed on the basis of a record of success. The intuition of the workers, however, becomes faulty, especially in relation to the behavior of engineered systems[1].

The problem escalates further in the case of modern systems of formwork since they have been developed with the objective of eliminating improvisation. These systems depend on exact element position, sequence disciplines, and sequence integrity. Even skilled workers who have been trained in traditional systems of formwork may sometimes attempt to "optimize" such systems through intuition because of their experience gained working with such systems[8]. They may remove some parts, vary sequences, or even replace certain components based on their intuition that their experience validates such improvisation. Literature reveals that the main causes of failure of such systems of formwork belong to the realm of misused experience rather than inexperienced workers.

5.3 Role of site pressure in skill degradation

Site pressure is far from a passive background influence: it is a potent, influential force with direct relevance for skill behavior. Construction projects have tight deadlines, cost limits, or contractual sanctions, which put significant stress in training, making it a non-productive exercise rather than a means for managing risks[3].

DOI: 10.17492/JPI/NICMAR/260542 *ISBN: 978-93-49790-68-1*

Within operations such as formwork work activities, pressure from the sites takes the form of accelerated pour rate schedules, shortened erection periods, early stripping requests, and provisions for tolerance. Labor knows quickly which regulations are enforced or which ones are flexible[3]. Unsafe workarounds can become logical behavior if they are rewarded but go unrewarded.

Such a trend, however, will eventually result in the adaptive degradation of skill. The adaptive degradation does not take a turn toward the best, but a turn that enables the survival in the pressures experienced. There will be skills that increasingly imply speed, output, verification, familiarity, but not necessarily correctness, stability, and accuracy in the process.

However, the literature stresses that not only does site pressure fail to support training, it indeed reprograms skill behavior. As such, it renders traditional training ineffective in its implementation. Any training approach that does not address site pressure remains incomplete.

6.0 Digital Training and Skill Assessment

Digital training and assessment are not a technological improvement, they are an epistemological shift—a different way of knowing, of measuring, of managing skills. Conventional systems base an indirect assessment of skill on experience, supervision, and certification. On the other hand, digital systems detect the skills of an employee directly through behavior.

6.1 Action recognition as a foundation for skill quantification

Action recognition technologies decompose work into observable and measurable behavioral units. Panel lifting, alignment, tie installation, bracing, and dismantling in formwork operations are not purely physical acts but expressions of decision-making, coordination, and understanding[5].

Expert performers also have consistent behavioral profiles: there are smooth trajectories of movement, few corrections, proper sequencing, and effective transitions. The smoothed behavioral profile reflects internalized knowledge of system behavior. Poor performers are hesitant, make repeated adjustments, sequence actions improperly, and manage movement inefficiently. These reflect cognitive uncertainty[3], [8].

Action recognition captures these differences quantitatively. This is critical, since skill differences in formwork are often subtle and cannot be reliably identified through casual supervision. Translating behavior into data, action recognition exposes the skill gaps that would otherwise remain hidden.

DOI: 10.17492/JPI/NICMAR/260542 ISBN: 978-93-49790-68-1

Most importantly, action recognition measures what workers actually do, not what they claim to know, or what supervisors believe they know. This shifts skill assessment from perception-based to evidence-based evaluation.

6.2 Productivity measurement as skill diagnosis

Traditionally, productivity has been a managerial metric, unrelated or only partially related to skill analysis. According to the literature, this is where the fundamental mistake occurs. Productivity, if measured at an action level, becomes a diagnostic indicator of the quality of skills.

Action-based productivity measurement reveals not only output rates but also how the output is achieved. Two workers may complete the same task in similar times but one may rely on repeated corrections and unsafe shortcuts while the other follows stable correct sequences. Aggregate productivity masks these differences; action-level productivity exposes them[5], [9]. Productivity data linked with action recognition can attribute delays accurately. For instance, material delays or congestion can be separated from internal skill deficiencies, such as poor sequencing or lack of coordination. These are important distinctions, not only for the sake of fairness in evaluation but also for effective training design. Productivity measurement now becomes a tool of diagnosing skills, not punishing performance.

6.3 Skill tagging and dynamic competency profiles

Skill tagging brings together workforce management and a specific digital assessment concept: "Operationalize Digital Assessment." Instead of categorizing employees in a business according to occupation and length of service, a workforce can be categorized according to skills and ability displayed by employees. These factors vary. As a person works, learns, or adjusts to a given system, these skills vary. It reflects the reality that skills have a life of their own—they become stronger or weaker or outdated, based on the situation[3].

Rational deployment is enabled through dynamic competency profiles, with risky deployments of workers, e.g., on "climbing operations" or "heavy wall pours," limited to those workers deemed ready through behavioral data, not through intuition-based deployment practices[2]. The literature emphasizes the importance of this process—from static classification to dynamic skill governance—in the effective and safe operation of contemporary formwork practices.

7.0 Digital Training Models for Formwork

Digital training models for formwork operations, therefore, mark an important shift in how skills pertinent to construction operations are understood, promulgated, and validated;

DOI: 10.17492/JPI/NICMAR/260542 ISBN: 978-93-49790-68-1

whereas traditional training paradigms normally operate on the assumption that skills can be transmitted through processes of explanation or observation, digital training is premised on the understanding that "formwork is space, formwork is physical, formwork is sequential, and formwork is systemic." In other words, digital training pedagogy is as important as the understanding of skills pertinent to the operations of formwork itself.

7.1 Why digital training is structurally different from traditional training

The traditional classroom learning is based upon knowledge transfer in an abstract sense, i.e., rules and procedures, and safety rules and procedures in a verbal or text format. This method assumes that workers can mentally transform the theoretical aspects of an operation into a physical activity at the site. The literature, however, indicates that this assumption does not hold true in the case of formwork operations because

- Many employees may not be formally educated or may not even know how to read
- Critical formwork behaviors (transfer of loads, pressure accumulation, and instability) are not visible
- Errors may emanate from the process of transitioning between steps, rather than from the performance of individual steps

This discrepancy is addressed by digital training by including learning as a fundamental element of visual representations or actions. Unlike traditional training that attempts to spur individuals to ask questions about the operations of a system by detailing its mechanisms, digital training shows its behavior when functioning correctly or incorrectly[6], [9].

7.2 Task-centric vs trade-centric training

The most important pedagogical contribution brought by digital training relates to a change from "trade-centric" learning to "task-centric" learning. Conventional training methods view "formwork carpenter" as a homogeneous skill set. In practice, there are a number of distinct tasks involved in the deployment of formswork, each of which differs in terms of associated risk, intellectual demand, or system interdependency, such as:

- Wall panel erection
- Slab Table Positioning
- Tie and Anchorage Installation
- Adjustment and alignment
- Stripping and relocation
- Execution of climbing sequence

The requirements of each task vary in terms of knowledge, attention, and decisions to be made during each task, and digital learning supports independence in each task by isolating each task and visualizing them individually in training. This has several advantages:

DOI: 10.17492/JPI/NICMAR/260542 ISBN: 978-93-49790-68-1

- Training is provided only for the tasks being performed.
- The workers can move from lower-risk to higher-risk tasks depending on the competence they have shown.
- Failures occur, and training gaps can be pinpointed to a task rather than the 'lack of skill'.

This task-centered model is particularly important with regard to advanced systems, such as climbing formwork systems, as an inaccurate execution of a task may result in failure of the system as a whole.

7.3 Role of simulation in conceptual skill formation

One of the main strengths that distinguishes advanced digital learning models is simulation. Using simulation allows workers to "see" invisible phenomena within the work domain, such as:

Increase of lateral concrete pressure with pour height and rate

- Redistribution of loads while stripping or climbing
- Effect of missing anchors or improper bracing
- Progressive collapse mechanisms

By representing the cause-and-effect relationship in a simulation, the divide is closed in that a simulation links procedural knowledge (how to) and conceptual knowledge (why one has to do it this way).

Such an issue is critical since "many accidents in formwork operations are caused, not by ignorance of the methods to be followed, but often by misjudgments in changing conditions." Simulations help workers "develop decision-making models that can be used to support decisions when conditions vary from 'normal'."

7.4 Why digital training must be closed-loop

The literature also strongly cautions that the training alone is not enough and that the absence of validation makes the virtual training another kind of static intervention, like classroom lectures. However, true effectiveness can only be guaranteed if a digital training environment is part of a closed loop system such that:

- Content for training is provided
- Worker behavior observed onsite
- Performance data is analyzed
- Training is refined based on gaps

Hence, the closed loop of the model guarantees that the supposition of learning does not rest, instead, on the verification of the behavior. It also converts the training process into an ongoing process of learning.

DOI: 10.17492/JPI/NICMAR/260542 *ISBN: 978-93-49790-68-1*

8.0 Training Assessment Frameworks: From Event-Based to Continuous Evaluation

Training assessment effectively remains the weakest link in the chain for construction workforce development. Much effort goes into training delivery, while a lackadaisical approach is seen in relation to training assessment. All literature concludes that training can be symbolic rather than functional without proper training assessment mechanisms.

8.1 Fundamental weakness of event-based assessment

Event-based assessment is dominant in the training provided in the construction industry due to administrative ease in monitoring. In event-based assessment, training sessions are regarded as a set of special occurrences such as inductions, toolbox talks, or training for safety purposes. They are often monitored on a simple satisfaction scale[3].

However, this approach is heavily disapproved of by literature because it focuses more on assessment by means of exposure rather than capability. Completions are not necessarily proof of comprehension, satisfaction is not proof of competence, and certificates are not proof of skills. What is not measured is whether this worker is competent in carrying out formwork activities in actual site conditions[4].

In the context of Formwork operations, such a limited ability becomes particularly dangerous because of their time-delayed and hidden nature of failure. The worker may be taking a class today, perform his/her actions improperly tomorrow, and ultimately cause a failure weeks down the line depending on how concrete, loading, or even stripping conditions change. At such a time, such a relation of training with failure becomes unclear, and a previous evaluation becomes falsely successful[3].

8.2 Multi-level nature of effective training assessment

The literature, conscious of the limitations of event-based models, therefore, goes on to propose multi-level training assessment frameworks that evaluate effectiveness across different dimensions of learning and performance. These emphasize that training must be assessed not only on what workers know, but on how they behave and what outcomes their behavior produces[8].

Assessment at the cognitive level checks if workers have grasped the essential principles underlying the work, like load paths, concrete pressure behavior, sequencing logic, and safety rationale. Although necessary, cognitive understanding is not enough in formwork operations, where execution under dynamic conditions is required[4].

The behavioural level is the most important for formwork. It has to do with whether workers on site apply correct techniques: correct spacing of ties, proper sequence of erection and stripping, pour rate limits and usage of safety systems. The literature clearly states that

DOI: 10.17492/JPI/NICMAR/260542 ISBN: 978-93-49790-68-1

formwork failures are rarely the result of a lack of knowledge; rather, they occur because knowledge is not consistently applied under pressure[4].

8.3 Continuous digital assessment as a solution

Rather, the literature is increasingly acknowledging that only continuum digital assessment offers viable solutions for the issues that are inherent in the more traditional models of assessment. Unlike the "event" assessment, digital assessment is not constructed around "checkpoints." Rather, it is designed to measure how the work is, in fact, performed[7].

Digital assessment systems record sequences of execution of tasks, time taken, efficiency achieved, corrections made, rework undertaken, and variations from standard practices. This enables a continuous process of providing behavioral evidence through assessment that transforms from a snapshot process of assessment to an ongoing process of assessment[6].

It's important to adopt this longitudinal perspective with regard to human factors in construction since skill levels are constantly changing. Factors like fatigue, pressure of construction sites, system changes, crew mix, etc., all continuously influence human behavior, making it essential to regularly assess whether skill degradation occurs, or not[9].

Most importantly, it is worth noting that the literature highlights that digital-based assessment changes training evaluation into a management instrument. In the context of operations like those of formwork, which are critical, it is of utmost importance that training is done through assessments that are critical as well[5].

9.0 Integration of Skill Gap Analysis, Training, and Deployment

9.1 Why fragmentation is a structural failure

Perhaps the most detrimental element of construction workforce management, as revealed through the relevant literature, lies in functional fragmentation. Skills assessment, together with training as well as workforce deployment, are often undertaken as separate processes, which are at times handled by separate entities.

Skill evaluation lacks formality, being an informal and subjective process, which entirely depends on the worker or on the availability of labor. Training programs are generic, standardized, and unrelated to the actual working conditions. Deployment is determined by the availability of labor, not on skill evaluation[1].

In operations relating to formworks, fragmentation brings about systemic danger. Workers, for instance, might have been trained but not utilized properly. The literature

DOI: 10.17492/JPI/NICMAR/260542 ISBN: 978-93-49790-68-1

indicates a big danger in operations, particularly in regard to accidents, caused by poor matching, for example, regarding skilled but not utilized workers and unverified workers.

This fragmentation endures because all the functions look locally sensible but are globally ineffective individually. Meaning, without their integration, a number of them are unable to affect the others.

9.2 Integrated model logic: Competence flow

There is a progressively stronger body of literature supporting the need for integrated workforce models, with an emphasis upon the idea of competence flow. Instead of viewing skill as an entity or an attribute, integrated models approach skill as a fluid entity.

The system's requirements are met through the following steps. It begins with the identification of system-specific competencies related to formwork operation. This is important since generic skills are considered inadequate to address the complexity of modern formwork systems. Accordingly, identification must include actual current practices such as "slab tables assembly," "wall anchorage execution," "climbing execution," "stripping during load redistribution," etc[7], [9].

Next, the actual capability of the worker is evaluated from the objective and behavioral perspective. This means that there is no assumption of competence; rather, it is measured. Additionally, there are exact and task-oriented skill deficits.

Training then takes place digitally, targeting areas of deficiency rather than providing overarching theory. The deployment of personnel is then governed by revised skills, meaning that everyone is given work that corresponds to their ability level.

Continual feedback provides updates to skill profiles, which actively closes the loop and enables adaptations as workers learn, get fatigued, or face new conditions.

9.3 Impact on safety and productivity

Literature has shown that competence-based deployment has the following implications: There is a fundamental change in the consequence for safety and productivity. If tasks that are considered risky are only allocated to authenticated workers, the probability of errors will be lowered at the onset. There will be improvement in the crew formation, thus curtailing possible interference-based delay[5].

Rework decreases with the completion of tasks with the first try. Compliance with safety rules becomes systematic rather than supervisory-oriented. Most importantly, higher productivity results not through pressure but through a sense of stability[5].

With respect to Formwork operations, in such circumstances, error propagation occurs very rapidly and has significant repercussions. Therefore, such integration in Formwork operations is not merely desirable but absolutely necessary

DOI: 10.17492/JPI/NICMAR/260542 ISBN: 978-93-49790-68-1

10.0 Strengthened Research Gaps and Explicit Justification of the Present Study

10.1 What existing literature fails to solve

Though significant developments have been recorded within construction training, productivity, and safety domains, literature presents many gaps. In most works, skill level is examined abstractly without specific competency models allied with formwork system complexity. Training research may only address learning outcomes. There may be no linkage or relation to application or deployment. Productivity studies may only show aggregate numbers, where individual competencies may vary. There may be demonstration of analysis ability in digital assessment research, but no linkage to operational models for human workforces. Hence, the industry accumulates knowledge without converting it into a practical control mechanism.

10.2 Why these gaps are critical for formwork operations

Formwork is a critical trade in terms of systems. Unlike finishing trades, where mistakes have less serious or indirect impacts, mistakes in formwork have serious implications for safety and other construction activities. The generic model does not capture this "concentration."

However, the absence of deployable and specific skill sets for the systems means that contractors continue to depend on judgment based on their own experience even for the latest systems. Such a contradiction defeats the full purpose of the latest form work technology available.

10.3 Explicit justification of the present study

The present study will directly address these unresolved issues by suggesting a structural integration of skill gap analysis, digital training, and deployment.

By defining the critical skills specific to formwork, objectively quantifying workforce skill gaps, linking training to verified behavioral change, and embedding skill data into deployment decisions, this study unlocks implementation going beyond analysis.

This positions the research not as an incremental improvement but as a system-level solution to a long-standing problem in formwork workforce management.

11.0 Conclusion

From the literature review section, it is clearly identified that skill gaps exist in formwork operation due to training and management of the working force rather than due to the intrinsic capacity of workers. It is assessed that training and management are no longer

DOI: 10.17492/JPI/NICMAR/260542 ISBN: 978-93-49790-68-1

effective due to an increase in the technical complexity of formwork. During past decades, formwork working practices have increased their type, starting with craft formwork and advancing forward to engineered systems of modular or climbing type. In spite of having an added type of working practice and formwork, training practices have applied less compared with its increased technological complexity. It is clearly identified that learners prefer informal training, and training assessment is possibly considered an area that is greatly affected. In compliance with training assessment, it is identified that actual performance cannot be assessed through training attendance. In contrast, checking performance through continuous methods using digital technologies is well recommended. From the literatures, it is clearly identified that digital training is effective if assessment outcomes are being used for checking actual workforce performance. In conclusion, the study shows significant research gaps that have been pointed out with regards to specific competency frameworks for formwork operations, which sets the context for the current study to offer a pragmatic approach to improved safety, productivity, and quality.

References

1. T. Terzioglu and G. Polat, ‘Formwork System Selection in Building Construction Projects Using an Integrated Rough AHP-EDAS Approach: A Case Study’, *Buildings*, vol. 12, no. 8, Aug. 2022, doi: 10.3390/buildings12081084.
2. ‘Rail Climbing System RCS C Climbing Formwork’.
3. P. S. Manjunath, M. B. Shravan, and D. B. B, ‘A Study on Assessment of Skill Gap to Enhance Workforce’, *International Journal of Management*, vol. IX, 2019.
4. H. Jadallah, C. J. Friedland, I. Nahmens, C. Pecquet, C. Berryman, and Y. Zhu, ‘Construction Industry Training Assessment Framework’, *Front. Built Environ.*, vol. 7, Aug. 2021, doi: 10.3389/fbuil.2021.678366.
5. M. Y. Cheng, A. F. K. Khitam, and H. H. Tanto, ‘Construction worker productivity evaluation using action recognition for foreign labor training and education: A case study of Taiwan’, *Autom. Constr.*, vol. 150, Jun. 2023, doi: 10.1016/j.autcon.2023.104809.
6. ‘A BIM-Based Tool for Formwork Planning in Reinforced Concrete Buildings’, *Journal of Engineering, Project, and Production Management*, Oct. 2025, doi: 10.32738/jeppm-2022-554.
7. R. Baskova, A. Tazikova, Z. Strukova, M. Kozlovska, and J. Cabala, ‘A Dynamic Model for Effective and Optimal Planning of Formwork in Construction Projects’, *Buildings*, vol. 13, no. 7, Jul. 2023, doi: 10.3390/buildings13071794.

DOI: 10.17492/JPI/NICMAR/260542 *ISBN: 978-93-49790-68-1*

8. P. Kumar and R. Mk, 'Advances in Consumer Research Enhancing Construction Workforce Efficiency through Digital Training: An Empirical Study', 2016. [Online]. Available: http://creativecommons.org/licenses/by/4.0/
9. K. Wu, S. A. Prieto, E. Mengiste, and B. García De Soto, 'Automated spacing measurement of formwork system members with 3D point cloud data'.

DOI: 10.17492/JPI/NICMAR/260542 *ISBN: 978-93-49790-68-1*