A Comprehensive Review of Prior Evidence

Report 5 in Volume 1 of the *Multiskilling in the U.S. Construction Industry* research series

SIMPLAR FOUNDATION

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A Comprehensive Review of Prior Evidence

Report 5 of 6 in Volume 1

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About the Series

This report is one of six reports in Volume 1 of *Multiskilling in the U.S. Construction Industry*. The series examines multiskilling through distinct research questions, evidence sources, and analytical methods. Volume 1 includes the largest field-collected dataset assembled to date on multiskilling as practiced in active U.S. construction projects and operations. It also includes controlled field trials, project records, evidence on employer workforce capability systems, a comprehensive review of peer-reviewed literature, and contractor safety context.

The research was conducted by the Simplar Foundation in collaboration with researchers affiliated with the University of Kansas, the University of North Carolina at Charlotte, and Arizona State University. Each report is designed to be read independently while contributing to the combined evidence base.

All published reports and related resources are available at the Simplar Foundation's Multiskilling Knowledge Hub (simplarfoundation.org/multiskilling).

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STUDY AT A GLANCE

A Comprehensive Review of Prior Evidence

Report 5 in Volume 1 of the *Multiskilling in the U.S. Construction Industry* research series

59	51	26	7
peer-reviewed studies published 1998–2026	journal articles in the literature sample	studies quantified project performance outcomes	studies used any form of onsite project data

KEY FINDINGS

1. **Nearly every peer-reviewed study (95%)** described multiskilling as valuable or emphasized its potential benefits.
2. **No prior studies** concluded that multiskilling was disadvantageous across any of the outcomes or conditions examined.
3. **Roughly a quarter (24%)** of prior studies conducted formal hypothesis testing supported by inferential statistics.
4. **More than half (54%)** relied on modelling and simulation methods without field-verified inputs.
5. **0 studies** directly measured project-performance effects on an active U.S. onsite project.
6. **0 studies** performed head-to-head comparisons of multiskilled and single-skilled crews for the same work sequences.

Reported performance impacts of multiskilling in prior literature

2% to 58%	0.3% to 58%	2% to 77%	2% to 53%
reduction in schedule durations	decrease in costs	improvement in production times	reduction in staffing requirements

DIRECTION OF THE EVIDENCE

Benefits reported for every outcome measured	95% describe multiskilling as valuable	No study concluded it was disadvantageous

Minimum and maximum performance effects reported across prior studies quantifying each outcome.

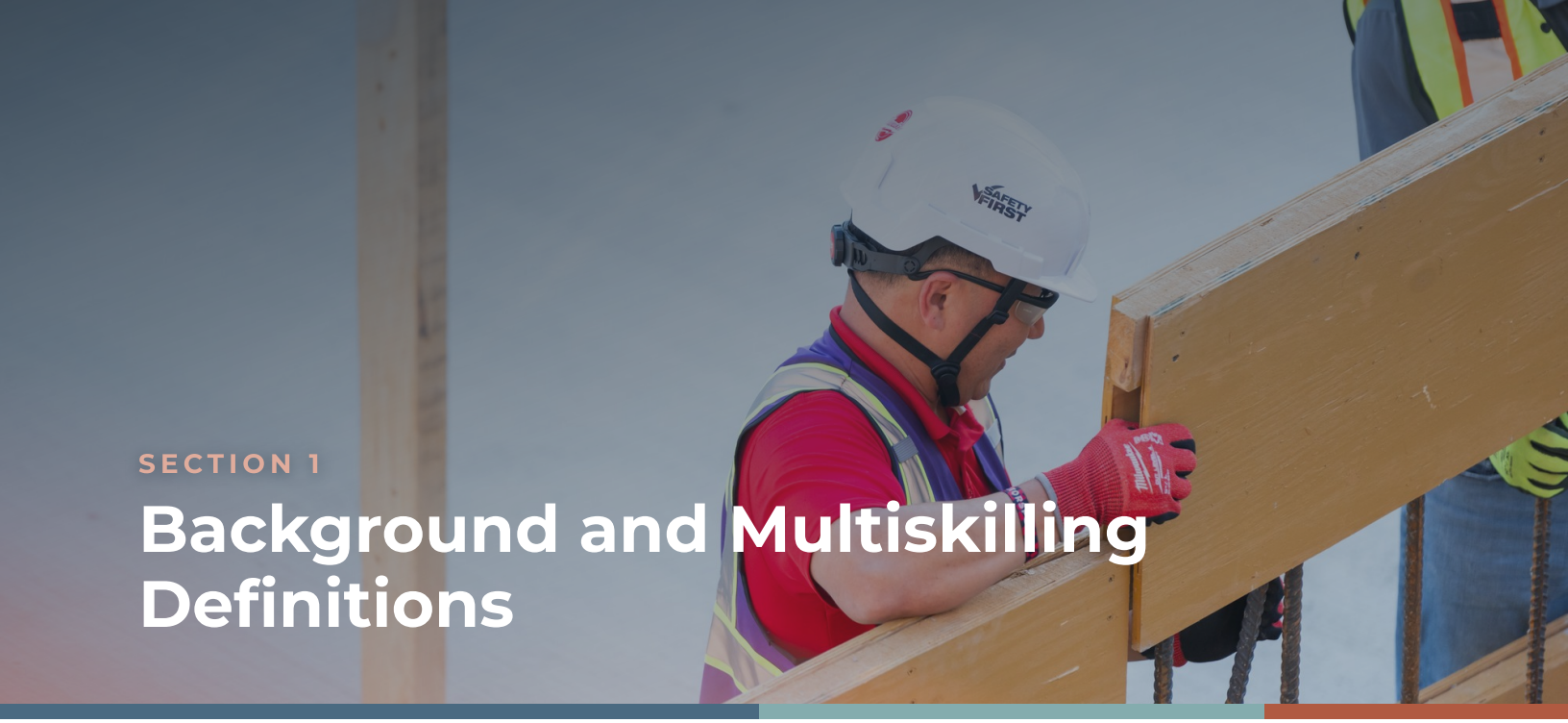
Executive Summary

Purpose of the Review

This report provides a comprehensive review of scientific studies focused on multiskilling. Multiskilling refers to a labor strategy in which workers or crews are qualified to safely and competently perform selected work activities across more than one trade, craft, or skill classification. This review examines the 59 studies on multiskilling published since the mid-1990s to examine how multiskilling has been studied, the project and worker outcomes reported, and the strengths and limitations of the available evidence concerning its use.

Key Findings

- Nearly every peer-reviewed study (95%) described multiskilling as valuable or emphasized its potential benefits.
- No prior studies concluded that multiskilling was disadvantageous across any of the outcomes or conditions examined.
- Roughly a quarter (24%) of prior studies conducted formal hypothesis testing supported by inferential statistics.
- More than half (54%) relied on modelling and simulation methods without field-verified inputs.
- 0 studies directly measured project-performance effects on an active U.S. onsite project.
- 0 studies performed head-to-head comparisons of multiskilled and single-skilled crews for the same work sequences.



SECTION 1

Background and Multiskilling Definitions

Multiskilling has been examined in construction research for nearly three decades as an approach to organizing and deploying workers who can safely and competently perform tasks across multiple trades and skill classifications. This body of research reflects continued interest in how the range and organization of workers' skills may influence construction planning, workforce utilization, and project execution.

Aims of this Review

For nearly three decades, research on multiskilling has focused on a broad range of potential effects, including cost, schedule, productivity, workforce requirements, work continuity, and labor utilization. Other studies have considered training, pay, employment duration, career development, worker acceptance, implementation barriers, and combinations of trades or skills that may be suitable for multiskilling. The research focus therefore extends beyond assigning workers to additional tasks; additionally, prior research has placed an emphasis on how multiskilling is developed, organized, implemented, and experienced by workers.

Despite the interest in multiskilling, the findings are not always easy to compare. Studies have defined multiskilling differently, examined it at the worker, crew, production-system, or project level, and used evidence from surveys, project records, field observations, simulation, and optimization models. As a result, findings that appear similar may reflect different forms of multiskilling, work settings, comparison methods, and performance measures.

A comprehensive review is therefore needed to clarify what has been examined, how the reported findings were produced, and where the evidence remains limited. The review also distinguishes outcomes observed in practice from results generated through models or hypothetical scenarios. This report brings together the main areas examined, research methods, data sources, reported outcomes, and trade or skill combinations in construction multiskilling research.

This literature review has three aims:

1 MAIN THEMES EXAMINED

Organize the existing studies into the main themes examined and describe how multiskilling has been defined and studied in construction during the past three decades.

2 FORMS OF EVIDENCE AND METHODS OF ANALYSIS

Assess the forms of evidence and methods of analysis used in prior studies, including the distinction between findings measured in practice and findings estimated through models, simulations, optimization methods, or hypothetical scenarios.

3 LIMITATIONS AND AREAS FOR FURTHER RESEARCH

Identify limitations in the available evidence and areas where further research is needed, particularly research based on active construction projects that documents the trades, skills, crew structures, and project conditions involved.

Through these aims, this report clarifies what is currently supported by the construction multiskilling literature, the conditions under which the reported findings were produced, and the questions that remain unresolved.

Definitions and Scope of Multiskilling

The construction literature has applied multiskilling to different units of the workforce and various scopes of work. Some studies define multiskilling through the range of work processes or trades that an individual worker can perform. Others focus on crews trained to complete more than one task or on training that extends workers' capabilities beyond their primary trade or work assignment. Table 1 presents selected definitions and descriptions from prior studies.

Table 1: Selected Definitions and Descriptions of Multiskilling in Prior Studies

Reference	Definition or description	Main emphasis
Burleson et al. (1998)	Multiskilling is a labor-utilization strategy in which workers possess skills appropriate for more than one work process and can be deployed flexibly across a project or organization. A multiskilled craft worker may apply skills and knowledge to tasks outside the traditional boundaries of the worker's original trade.	Flexible deployment across work processes and trade boundaries
Gomar et al. (2002)	A multiskilled workforce consists of workers whose range of skills allows them to participate in more than one work process.	Participation in multiple work processes
Nasirian et al. (2019a)	Multiskilling, or cross-training, refers to using crews that are trained to perform more than one task.	Crew capability across tasks
Nasirian et al. (2019c)	In off-site construction, multiskilling involves training workers in several craft skill sets so that they can be assigned to different workstations when needed.	Worker movement across production workstations
Ahmadian Fard Fini et al. (2016)	Multiskilling refers to using workers who can perform more than one trade, either because they already possess the capability or because it has been developed through training.	Individual capability across trades
Albalawi et al. (2023)	Multiskilling involves training craft professionals to acquire skills and perform tasks in trades in addition to their primary trade. Multiskilled craft workers may remain certified and highly competent in a primary trade without being limited to work within that trade.	Expansion beyond the primary trade or duties

The definitions differ in three important respects. First, some apply multiskilling to an individual worker, while others apply it to a crew. Second, the additional capability may extend across work processes, tasks, trades, or production workstations. Third, some definitions include skills that workers already possess, while others emphasize cross-training as the means through which the additional capability is developed.

Despite these differences, the definitions share a common basis. A worker or crew is considered multiskilled when capable of performing another distinct type of work beyond a primary trade or work assignment. The literature describes this primary area of work using terms such as primary trade, original trade, primary duties, primary task, or assigned workstation.

For consistency, this report uses the terminology provided in Table 2.

Table 2: Multiskilling Terminology Used in This Report

Term	Meaning used in this report	Supporting studies
Primary trade or work assignment	The trade, duties, task, or workstation to which a worker is primarily assigned before multiskilling is considered. In onsite construction, this generally refers to the worker's primary or original trade or primary duties. In off-site production, it may refer to the worker's primary task or assigned workstation.	Burleson et al. (1998); Ahmadian Fard Fini et al. (2016); Nasirian et al. (2019c); Albalawi et al. (2023)
Additional skill	A distinct capability that enables a worker to perform another trade activity, task, work process, production operation, or workstation assignment beyond the worker's primary trade or work assignment.	Burleson et al. (1998); Gomar et al. (2002); Nasirian et al. (2019a, 2019c); Ahmadian Fard Fini et al. (2016); Albalawi et al. (2023)
Cross-training	Training that enables a worker to perform one or more tasks or work processes beyond the worker's primary trade or work assignment. In this report, cross-training refers to the process used to develop additional capability, while multiskilling refers to the resulting worker capability or workforce arrangement. Some studies use the two terms interchangeably.	Nasirian et al. (2019a, 2019b, 2019c); Albalawi et al. (2023)

DEFINITION USED IN THIS REPORT

Multiskilling is the ability of an individual worker to perform one or more distinct types of work beyond the worker's primary trade or work assignment. The additional work may involve another trade, task, work process, or, in off-site construction, a production workstation that would otherwise be assigned separately. A worker may already possess these capabilities or acquire them through cross-training.

At the crew level, multiskilling refers to a crew in which workers are trained or otherwise able to be reassigned across more than one distinct task or type of work. A crew is not considered multiskilled solely because it includes workers from different trades.

SECTION 2

Methodology

This section describes how the literature on multiskilling in construction was identified, screened, and reviewed. It also explains how the studies were classified and how the findings presented in this report were summarized.

Literature Search and Screening

Literature searches were conducted through scientific databases, including Scopus, Web of Science, and ScienceDirect. Google Scholar and University libraries were used as supplemental search sources to identify additional peer-reviewed studies that did not appear in the initial database searches.

The search terms included variations of multiskilling, multi-skilled labor, cross-trained workers, labor flexibility, workforce flexibility, construction labor productivity, crew productivity, labor utilization, workforce planning, and project performance. These terms were searched individually and in combination with construction-related keywords to account for differences in terminology across the literature.

Studies were included when multiskilling, cross-training, or the performance of more than one distinct trade, task, work process, or production operation formed a substantive part of the study. Eligible studies addressed onsite construction, off-site or prefabricated construction, construction workforce data, or construction production and prefabrication settings.

Industry reports, trade articles, presentations, news articles, opinion pieces, and other non-peer-reviewed sources were excluded.

Study Classification and Synthesis

The included studies were reviewed to catalogue information on publication year and type, geographic context, data source, method of analysis, research themes, the form of multiskilling examined, trade or skill combinations, project-performance outcomes, and outcomes for workers. Studies could be assigned to more than one research theme when they addressed several areas. The use of inferential statistical testing was recorded separately as present or absent.

Geographic context was based on the stated location of the project, production facility, worker sample, or dataset. When no project or data location was reported, the study location was recorded as not specified and the authors' country or regional affiliation was noted.

For performance-related findings, the basis of evidence was also recorded. Findings were classified according to whether they were based on direct field observation, project records, worker or industry surveys, simulation, optimization, scheduling analysis, scenario analysis, or conceptual discussion. Quantified outcomes were also reviewed according to their comparison basis, including multiskilled versus single-skilled labor, one multiskilling strategy versus another, a modeled scenario versus a baseline, or an optimized schedule or allocation model versus a conventional approach.

Findings were recorded as reported in the original studies. When studies provided raw values rather than percentage changes, percentage changes were calculated from the values reported by the authors. Publications were counted separately in the literature summary. However, when multiple publications used the same project, production setting, or dataset, those repeated cases were noted when discussing the number of independent projects or cases represented.

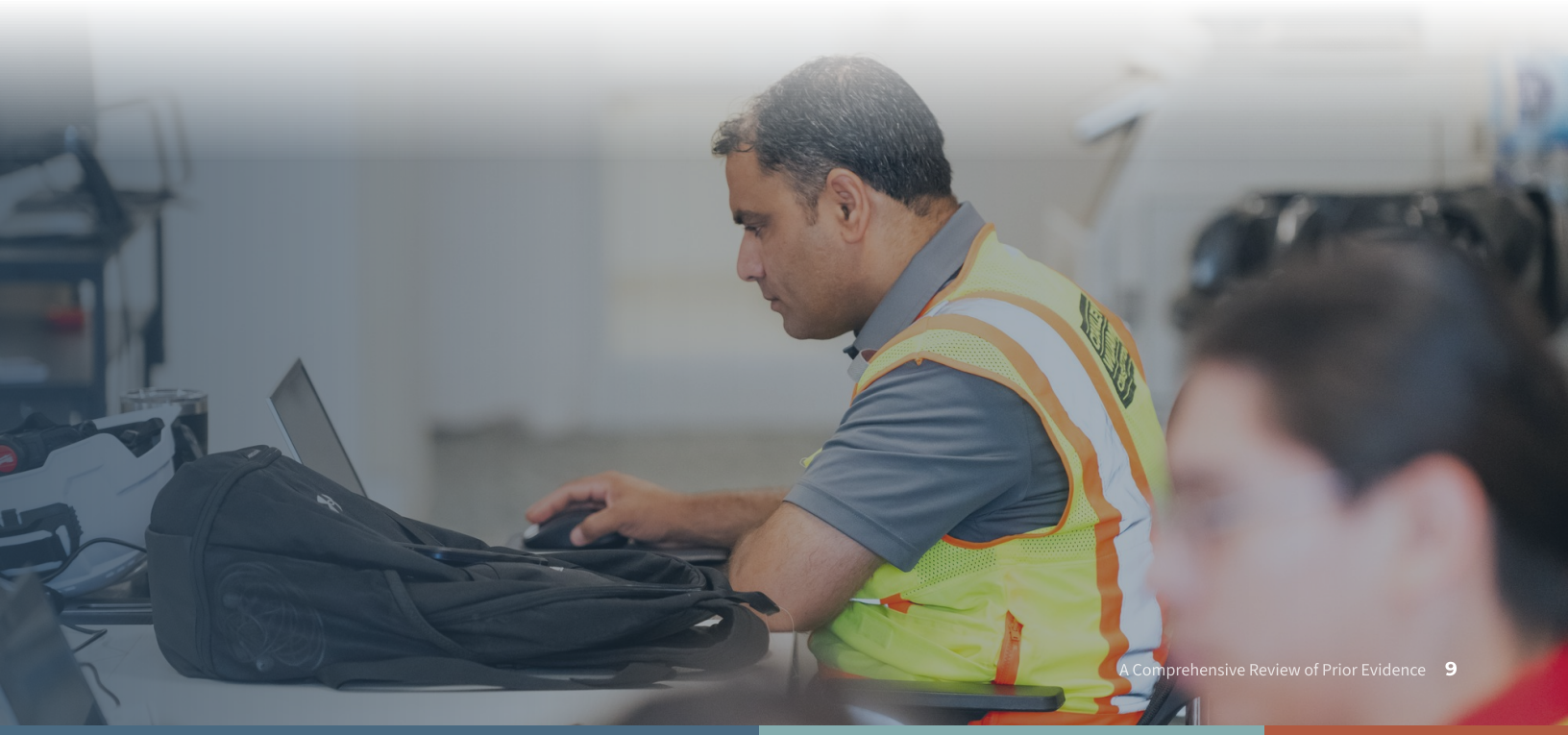
The studies varied in setting, analytical method, comparison basis, unit of analysis, and performance measure. Their findings were therefore summarized descriptively rather than combined into one overall estimate. The reported ranges show the results found across the reviewed studies and should not be interpreted as the effect expected on a typical construction project.

Final Literature Sample

The final sample included 59 peer-reviewed studies published between 1998 and mid-2026. The sample comprised 51 journal articles, 7 conference papers, and 1 master's thesis. Key publication outlets included the Journal of Construction Engineering and Management, Automation in Construction, Construction Management and Economics, and Engineering, Construction and Architectural Management. Conference proceedings from the Construction Research Congress and the Association of Researchers in Construction Management were also represented. Table 3 summarizes the key characteristics of the literature sample.

Table 3: Review Sample at A Glance

Category	Summary
Final sample	59 peer-reviewed studies
Publication years	1998 to mid-2026
Peer-reviewed publication types	51 journal articles; 7 conference papers; 1 master's thesis
Main search sources	Scopus, Web of Science, ScienceDirect, Google Scholar, University Libraries
Key publication outlets	Journal of Construction Engineering and Management; Automation in Construction; Construction Management and Economics; Engineering, Construction and Architectural Management; Construction Research Congress; Association of Researchers in Construction Management
Geographic coverage	U.S.-based and international studies
Excluded sources	Industry reports, presentations, news articles, trade articles, and other non-peer-reviewed sources



SECTION 3

Profile of the Reviewed Studies

This section summarizes the basic profile of the studies included in the review. It describes when the studies were published, the types of publication represented, and the geographic contexts covered by the prior multiskilling literature.

Overview of the Literature Sample

The 59 reviewed studies were published between 1998 and mid-2026. The sample included peer-reviewed journal articles, conference papers, and a master's thesis. The publication timeline shows that multiskilling has been discussed in construction research since the late 1990s, with studies appearing across different periods rather than being concentrated in a single time frame.

CHARACTERISTICS OF THE REVIEWED STUDIES

PUBLICATION PERIOD	1998–mid-2026: 59 studies
PEER-REVIEWED PUBLICATION TYPE	51 journal articles; 7 conference papers; 1 master's thesis
GEOGRAPHIC COVERAGE	U.S.-based: 15 studies; Non-U.S./international: 28 studies; Multi-country: 1 study; Not specified: 15 studies

Publication Timeline

Figure 1 shows the annual number of reviewed multiskilling studies published between 1998 and mid-2026. Publication activity was highest between 1998 and 2010, with 22 studies, followed by 20 studies published between 2011 and 2020. The remaining 17 studies were published between 2021 and mid-2026.

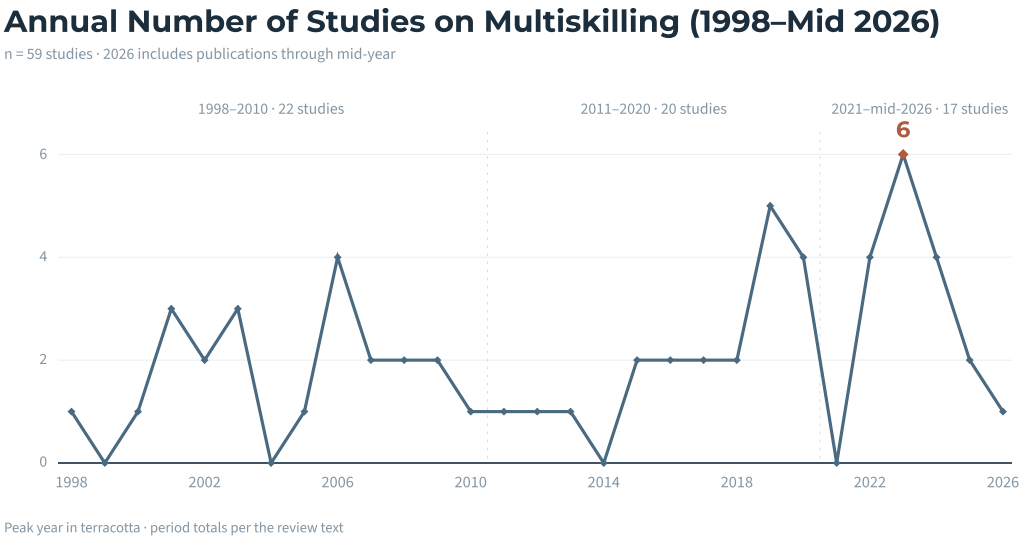


Figure 1: Publication Timeline of Reviewed Studies

Publication Type

The reviewed studies were also grouped by publication type to show the kinds of peer-reviewed sources represented in the literature sample. Journal articles made up the largest share of the reviewed studies, followed by conference papers. A master's thesis represented a small portion of the sample.

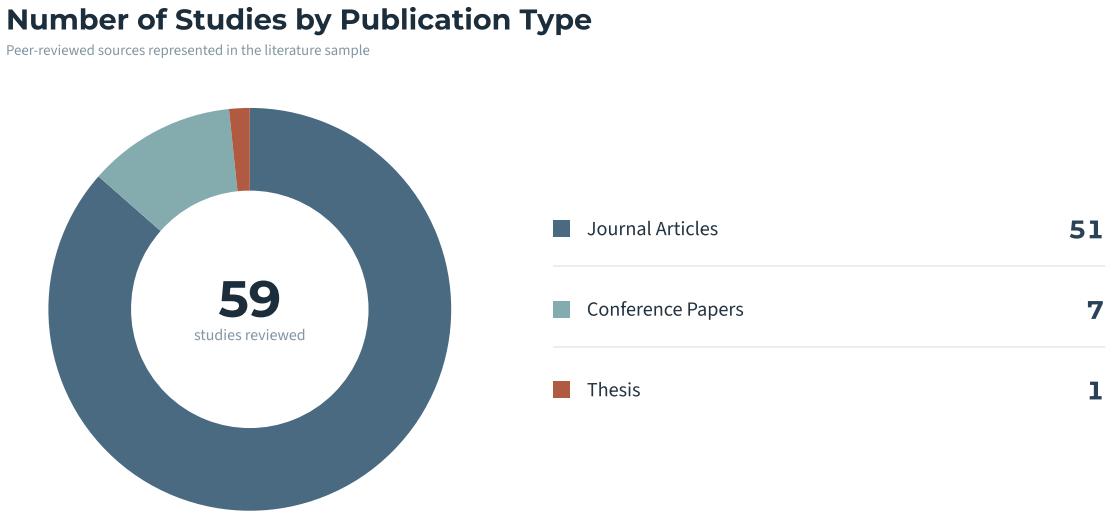


Figure 2: Publication Type Distribution

Geographic Coverage

The reviewed studies represented several geographic contexts. Some were based on U.S. construction data, workers, or project examples. Others examined construction settings outside the United States, including country-specific contexts. One study included data from more than one country, while 15 studies did not report a specific project, workforce, production, or dataset location.

Geographic context was based on the stated location of the project, production facility, worker sample, or dataset. When no project or data location was reported, the study location was recorded as not specified and the authors' country or regional affiliation was noted. These categories should therefore be interpreted as study-context classifications rather than direct field-project locations.

Table 4: Geographic Coverage of Reviewed Studies

Geographic category	Number of studies	Description
U.S. Based	15 (25%)	Studies using U.S. construction data, U.S. workers, U.S. industry context, or U.S.-based project examples
Non-U.S./international	28 (47%)	Studies based on project, workforce, production, or other study contexts outside the United States
Multi-country	1 (2%)	Study using project or data evidence from more than one country
Not specified	15 (25%)	Studies for which a specific project, workforce, production, or dataset location was not identified; author affiliation was noted separately

SECTION 4

Review of Prior Research Methods

Prior research has examined multiskilling through a range of approaches, from field studies and surveys to simulation, optimization, and conceptual models. This section examines the data sources used, the scale and types of data reported, the primary methods of analysis, and the extent to which prior studies applied inferential statistical testing.

Data Sources Used in Prior Studies

The reviewed studies used different types of data sources to examine multiskilling. These included survey and interview data, project and firm records, onsite observations, off-site production data, model-based or conceptual sources, and secondary industry datasets. In this report, data sources refer broadly to the information, records, cases, model inputs, or conceptual material on which a study was based.

Data sources are important because they shape the type and defensibility of conclusions that can be drawn from each study. For example, surveys, interviews, Delphi panels, and discussion forums help explain how workers, managers, and industry experts understand multiskilling, including motivation, training needs, implementation conditions, and perceived benefits or barriers. These sources are useful for understanding experience and judgment, but they usually do not provide direct measures of work output or measure the effect of multiskilling on project outcomes. Other data sources such as project records, firm records, and monitoring data are more closely connected to project performance, although they may not fully separate the effect of multiskilling from other project conditions. Direct onsite observations and off-site production data provide closer evidence of work execution because they can document tasks, worker assignments, labor utilization, or production output. Benchmark, model-plant, and conceptual sources are useful for testing possible workforce strategies under defined assumptions, but their findings are better interpreted as scenario-based or conceptual evidence rather than field-measured effects. For this reason, the data-source profile helps show not only how prior studies examined multiskilling, but also the type and strength of evidence supporting their conclusions.

Table 5: Data Sources Used in Reviewed Studies

Data source	Number of studies	Description
Benchmark, model-plant, or conceptual sources	18 (31%)	Hypothetical cases, benchmark cases, model-plant examples, conceptual studies, or theoretical frameworks
Project records, firm records, or monitoring data	12 (20%)	Project documents, company records, meeting reports, monitoring data, or information from prior projects
Interviews, contextual site visits, Delphi panels, or discussion forums	12 (20%)	Information through conversations, expert input, site visits, or group-based industry discussions
Surveys or questionnaires	11 (19%)	Structured responses collected through survey or questionnaire instruments
Off-site or factory production data	9 (15%)	Prefabrication, modular, plant, or shop-floor production data
Published literature or prior studies	7 (12%)	Review-based studies relying mainly on existing literature or data from prior studies
Secondary or industry datasets	6 (10%)	Existing structured datasets such as certification records, exam completions, job advertisements, workforce databases, or industry labor data
Direct on-site project or field data	2 (3%)	Direct observation or recording of work activities from active construction projects. In one study, the observations supported broader workforce-management principles; in the other, field data were used as inputs to a simulation-based analysis

Note: Counts overlap because some studies used more than one data source; therefore, percentages do not sum to 100%. Site visits were included in the interview and expert-input category when they provided contextual or participant-based information rather than direct observation of active work.

Benchmark, model-plant, or conceptual sources formed the largest category, appearing in 18 studies. Project and firm records and interviews, contextual site visits, Delphi panels, or discussion forums each appeared in 12 studies. Surveys or questionnaires appeared in 11 studies, followed by off-site or factory production data in 9 studies. Direct onsite data collected through observation of active construction work appeared in only two studies. This distribution shows that much of the prior evidence on multiskilling is based on modeled, record-based, or participant-based sources rather than direct observation of multiskilled work on active construction projects.

Reported Scale of Data Used in Prior Studies

In addition to differing in data source, the reviewed studies varied considerably in the scale of data reported (see **Table 6**). Reporting the scale of data used in prior studies helps distinguish the breadth of the evidence from its direct relevance to project performance. For example, large datasets, such as certification records or job advertisements, can identify broad skill patterns, certification activity, and labor-market demand. However, they do not directly measure how multiskilling affects cost, schedule, productivity, or labor utilization on active projects. In contrast, project cases, production cases, and field observations are usually smaller in number but are closer to actual construction work settings, although they may not always isolate the effect of multiskilling.

Therefore, the reported quantities are presented to show the type and scale of evidence behind the reviewed studies, not to rank the strength of the studies based on sample size alone.

Table 6: Reported Scale of Evidence by Data Type

Type of data	Description	Data points
Project, firm, or model-plant data	Project- and production-based categories came from case projects, direct field observations, off-site production settings, and project, firm, or model-plant data.	6 identifiable cases; 1 modeled construction program comprising 10 hypothetical projects; plus an unreported number of projects across 25 firms monitored over 5 years
Onsite project cases	Real projects used as case applications without direct observation of work activities	6 distinct projects
Off-site or factory production cases	Actual off-site, plant, modular, prefabrication, or shop-floor production cases	13 facilities/cases
Field observations	Active-project observations or recorded work-activity data reported in studies that discussed multiskilling. In some cases, these observations supported broader workforce-management principles rather than directly measuring multiskilling effects	36 projects
Interviews and expert input	Interviews, expert panels, discussion forums, Delphi input, or similar participant-based input	297 participants
Surveys and questionnaires	Completed survey or questionnaire responses from workers, firms, or other participants	6,024 responses/participants
Certification or exam records	Certification, assessment, or exam-based records and participants	663,094 records/participants
Job advertisements or labor-market datasets	Job advertisement or labor-market records used as structured datasets	1,415,436 records

Note: Some studies reported more than one kind of data point. In those cases, the same study was represented in each relevant category. The categories represent different units and should not be added together.

Interview and survey data were collected from workers, managers, firms, and other industry participants. These data were used mainly to capture worker characteristics, training, receptiveness, implementation conditions, and other perception- or experience-based information. Project-based categories came from case projects, direct field observations, off-site production settings, and project or firm records. Many of these data were tied to actual work settings, work activities, and project conditions, although some project-based analyses used modeled or hypothetical applications. Certification records and job advertisements contained much larger quantities of data and were used to identify broader patterns in certification activity, skill combinations, and labor-market demand. Because the categories represent different units of evidence, the reported quantities should not be compared as though they measure the same type of data or provide the same type of support for project-performance conclusions.

Methods Used to Analyze Multiskilling

The reviewed studies used different analytical approaches to examine multiskilling (see Table 7). The method of analysis is important because it affects how the findings should be interpreted and how defensible they are. Model-based, simulation, and optimization studies can compare workforce strategies under controlled assumptions, but their results represent estimated or scenario-based outcomes rather than directly measured field effects. Statistical studies can test relationships or group differences in survey, certification, workforce, or project data. Descriptive and qualitative studies can explain implementation patterns, worker characteristics, and practical conditions, but they provide more limited evidence for estimating project performance effects.

Table 7: Methods Used to Analyze Multiskilling in Reviewed Studies

Method of analysis	Number of studies	Description
Model-based, simulation, or optimization analysis	32 (54%)	Mathematical models, scheduling models, simulations, optimization, genetic algorithms, digital twins, or scenario testing to compare workforce strategies or estimate outcomes
Statistical analysis	11 (19%)	Formal statistical methods, such as regression, correlation, chi-square tests, significance tests, or other comparison tests
Descriptive quantitative analysis	6 (10%)	Numerical summaries using counts, percentages, averages, mean scores, cross-tabulations, or before-and-after comparisons, without using formal statistical tests
Qualitative or conceptual analysis	5 (8%)	Implementation processes, organizational practices, or frameworks interpreted through narrative or case-based discussion
Decision-support or ranking methods	3 (5%)	Scoring, ranking, fuzzy methods, MCDM, AHP, TOPSIS, PROMETHEE, or similar methods used to evaluate or rank alternatives
Literature review or synthesis	2 (3%)	Review and synthesis of prior research rather than new project, worker, or model-based analysis

Note: Percentages may not sum up to 100% because of rounding.

More than half of the reviewed studies used model-based, simulation, or optimization approaches as their primary method of analysis. These methods are useful for comparing workforce strategies, testing assignment rules, and estimating possible cost, schedule, productivity, or workforce outcomes under defined assumptions. However, they should not be interpreted in the same way as outcomes measured directly from active construction projects. Statistical analysis was the primary method in 11 studies, while 6 studies used descriptive quantitative analysis. 5 studies used qualitative or conceptual analysis, 3 used decision-support or ranking methods, and 2 relied primarily on literature review or synthesis. This method profile helps explain why many reported performance findings in the literature are best interpreted as modeled, estimated, or scenario-based results rather than direct measurements of multiskilling effects in the field.

Use of Inferential Statistical Testing

The review also examined whether prior studies supported their findings with inferential statistical testing, that is, formal hypothesis tests (see Table 8). In practical terms, these tests ask whether a reported difference or relationship is strong enough to be treated as a meaningful pattern rather than the result of normal variation in the data.

This distinction matters because construction performance reflects many conditions at once. Cost, schedule, productivity, labor utilization, and workforce requirements are influenced by crew size, supervision, work sequencing, congestion, weather, material availability, project type, worker experience, and other site conditions. A reported improvement may be related to multiskilling, or it may reflect one of these other factors. Hypothesis testing is one way to assess whether an observed difference is too large to be explained by ordinary variation alone.

In this report, inferential statistical testing refers to formal procedures for testing relationships, group differences, effects, or statistical significance. Examples include significance tests on regression coefficients, correlation tests, chi-square tests, paired t-tests, analysis of variance, confidence intervals, and reported significance levels or p-values. In the scientific literature, the use of inferential testing is typically required to test a hypothesis and defend a result as having statistical significance for defensibility.
Whether a study used inferential testing was recorded separately from its primary method of analysis, because the two do not always align. A survey-based study may use regression to formally test the relationship between worker characteristics and multiskilling, while an optimization study may estimate cost or schedule savings without ever testing those results for statistical significance. Descriptive statistics, model outputs, optimization results, sensitivity analyses, rankings, and before-and-after comparisons were counted as inferential testing only when a formal significance test was applied.

Fourteen of the 59 reviewed studies (24%) used inferential statistical testing. The remaining 45 studies (76%) relied on descriptive summaries, qualitative analysis, model outputs, optimization results, ranking methods, or literature synthesis without formal statistical testing.

Table 8: Use of Inferential Statistical Testing in Reviewed Studies

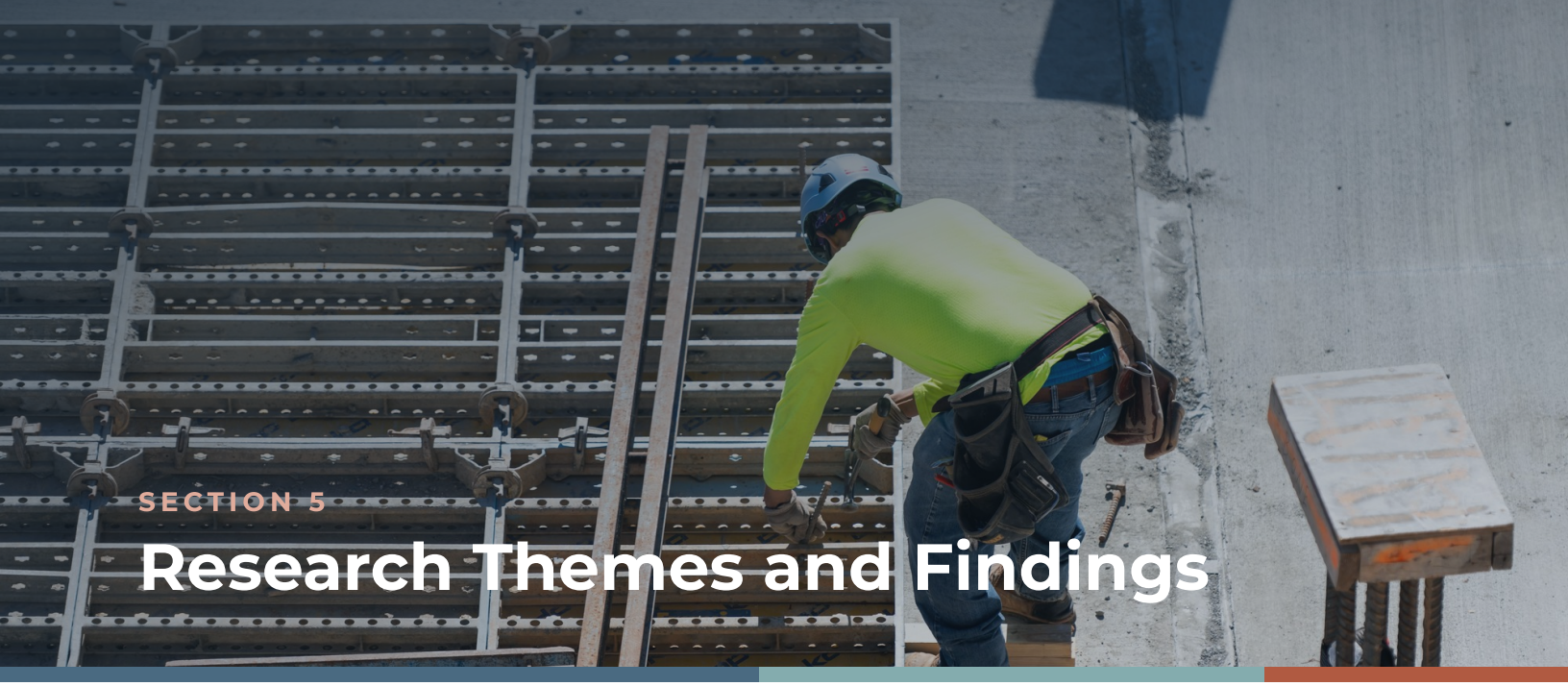
Inferential testing category	Number of studies	Percentage	Description
Used inferential statistical and hypothesis testing	14	**24%**	Studies that applied formal statistical procedures, including hypothesis tests, to evaluate relationships, differences, effects, or statistical significance
Did not use inferential statistical and hypothesis testing	45	76%	Studies that did not apply formal statistical testing

WHY THIS MATTERS FOR INTERPRETING THE EVIDENCE

In the prior literature, **14 of the 59** reviewed studies used inferential statistical and hypothesis testing. This distinction matters because a modeled cost saving, an optimized schedule, or a case-based improvement does not provide the same type of evidence as a statistically tested result from observed data.

Model-based studies can show what may happen under stated assumptions. Case-based studies can show how multiskilling was applied in a specific setting. Descriptive comparisons can show differences reported in a study. Statistical hypothesis testing adds another layer by testing whether a pattern in the data is strong enough to be treated as more than normal project variation.

This means that many findings in the prior literature are useful for understanding possible benefits, planning approaches, and implementation options, but fewer studies provide statistically tested evidence that multiskilling itself produced the reported performance differences.



SECTION 5

Research Themes and Findings

The 59 reviewed studies were coded under five research themes to describe how prior studies have approached multiskilling in construction. Several studies addressed more than one issue, so multiple themes were assigned where appropriate. As a result, the theme counts are not mutually exclusive and do not sum to 59.

The purpose of this classification was to identify the main areas emphasized in the literature, including the optimal use of multiskilled labor, project performance impacts, workforce development, implementation and adoption, and skill-combination patterns.

Table 9: Main Themes of Focus in Prior Multiskilling Studies

Main area examined	Number of studies	Description
Optimal use of multiskilling	39 (66%)	Studies that examined how multiskilled labor can be planned, assigned, scheduled, allocated, or optimized across activities, crews, workstations, or projects
Project performance impacts of multiskilling	26 (44%)	Studies that reported or estimated project or production performance outcomes associated with multiskilling, including cost, schedule, productivity, and workforce requirements
Workforce development, training, and strategy	21 (36%)	Studies that examined multiskilling in relation to training, worker motivation, skill development, employability, employment stability, career development, skill-shortage response, or long-term workforce strategy
Implementation and adoption of multiskilling	14 (24%)	Studies that examined how multiskilling can be introduced, supported, or managed in construction or construction-related work settings, including drivers, barriers, feasibility, acceptance, company practices, and organizational readiness
Skill combinations in multiskilling	8 (14%)	Studies that identified, compared, or analyzed the specific skills, trades, task areas, or work processes combined to create multiskilled capability

Note: Studies could be assigned to more than one theme; therefore, the theme counts are not mutually exclusive and sum to more than the 59 studies reviewed.

OPTIMAL USE OF MULTISKILLING

The largest theme was optimal use of multiskilling, which appeared in 39 studies. These studies focused on how multiskilled labor can be planned, assigned, scheduled, allocated, or optimized. Much of this work treated multiskilling as a labor-planning or resource-allocation strategy, with emphasis on resource-constrained scheduling, crew composition, task assignment, process integration, workforce allocation, and multi-project scheduling. In these studies, the main concern was how multiskilled workers should be deployed across activities, crews, workstations, or projects to make better use of available labor.

PROJECT PERFORMANCE IMPACTS OF MULTISKILLING

The second theme included 26 studies that reported or estimated project or production performance outcomes associated with multiskilling. These studies examined outcomes such as cost, schedule, productivity, and workforce requirements. This theme was limited to project- or production-level impacts. Worker-centered outcomes such as motivation, wages, employability, job satisfaction, or employment duration were not included under this theme unless they were directly connected to project or production performance. The studies in this group provide the main evidence base for understanding the project and production outcomes that prior research has associated with multiskilling.

WORKFORCE DEVELOPMENT, TRAINING, AND STRATEGY

The third theme included 21 studies that examined multiskilling as part of workforce development, training, skill-shortage response, worker motivation, employment stability, or long-term workforce strategy. These studies focused on how workers develop broader capabilities, how receptive they are to additional training or nontraditional work practices, and how multiskilling may support a more flexible and sustainable construction workforce. Worker motivation was included in this theme because motivation is closely related to craft workers' willingness to acquire and use additional skills. Studies in this area discussed issues such as higher pay, continuous learning, career development, job security, skill evolution, and worker readiness for broader technical or management responsibilities.

IMPLEMENTATION AND ADOPTION OF MULTISKILLING

Implementation and adoption appeared in 14 studies. These studies examined how multiskilling can be introduced in construction or construction-related work settings. Common topics included drivers, barriers, feasibility, worker and employer acceptance, company practices, organizational readiness, union or non-union context, and implementation strategies. This theme highlights that multiskilling depends not only on individual worker capability, but also on how firms structure, support, and manage the use of broader skills in practice.

SKILL COMBINATIONS IN MULTISKILLING

Skill combinations were a substantive area of examination in 8 studies. These studies focused on identifying, comparing, or analyzing the specific skills, trades, or task areas combined to create multiskilled capability in construction. This theme is important because multiskilling is not simply about increasing the number of tasks a worker can perform. Its usefulness depends on the relationship between the skills being combined and how those skills support actual labor deployment. Studies in this theme examined issues such as skill affinity, trade pairings, and job-advertisement skill requirements. The studies show that the value of multiskilling depends not only on the number of skills combined, but also on the compatibility and practical usefulness of those combinations.

Optimal Use of Multiskilling

Thirty-nine studies examined how multiskilled labor could be planned, assigned, scheduled, and allocated across activities, crews, workstations, or projects. Most sought to determine the workforce arrangement that made the best use of available labor under a defined set of project or production conditions.

Across these studies, there was no single optimal multiskilling strategy. The preferred arrangement depended on the objective being pursued, the pattern of labor demand, the skills available, and the constraints of the project or production system. Some studies sought to minimize project duration or labor cost, while others focused on balancing workloads, reducing workforce fluctuations, limiting additional hiring, improving production flow, or maintaining employment continuity. In some cases, these objectives competed with one another. For example, minimizing immediate project cost or duration did not always align with goals such as maintaining workforce continuity, supporting learning, or developing broader worker capabilities.

Workforce planning involved decisions about the proportion of single-skilled and multiskilled workers, the number and type of skills each worker should possess, crew composition, and the choice between training existing workers and hiring workers with broader capabilities. The studies examined arrangements ranging from dual-skilling and partially multiskilled crews to broader trade groupings and full cross-training. Several studies found that targeted multiskilling configurations could provide flexibility without requiring the entire workforce to become multiskilled.

Worker assignment generally involved directing available skills toward areas where labor demand exceeded capacity. In onsite project models, workers were assigned across activities and crews according to project schedules, labor requirements, and skill availability. In off-site production, workers were reassigned among workstations to balance capacity and support bottleneck operations. Multi-project studies extended the same approach across several projects competing for the same workforce.

The assignment approaches became more detailed over time. Earlier studies commonly treated workers according to the trades or tasks they could perform. Later studies also considered competency, productivity, experience, learning, cooperation among workers, changes in skill level, and the time and cost involved in switching between skills. These additions recognized that workers who possess the same skill may not perform it at the same level and that reassignment can create costs as well as flexibility.

The central finding from this theme is that the usefulness of multiskilling depended less on maximizing the number of multiskilled workers and more on matching worker capabilities with the timing and location of labor demand. Multiskilling provided the greatest modeled value when broader skills were assigned to a specific resource constraint, workload imbalance, or production bottleneck.

Most studies in this theme relied on scheduling models, optimization methods, simulations, or defined project and production cases. They provide structured approaches for planning and allocating multiskilled labor, but there is limited evidence showing how these deployment strategies perform when implemented during day-to-day onsite construction.

Key Finding: The best use of multiskilling depended on the workforce objective, labor-demand pattern, available skills, and project or production constraints. Effective planning required selecting an appropriate mix of workers and assigning their capabilities where they addressed a specific labor or workflow need.

Project Performance Impacts of Multiskilling

Of the 59 reviewed studies, 26 examined at least one measurable project performance outcome. Because a study could examine more than one outcome, the counts across outcome categories exceed the number of studies.

Project performance outcomes were defined as measurable effects on project delivery, production, or workforce requirements. Worker outcomes, including motivation, wages, skill development, and employment continuity, are discussed separately in the following section.

Four project performance outcomes were identified: schedule, cost, workforce requirements, and productivity (see Table 10). Schedule was examined most frequently, followed by cost. Workforce requirements and productivity received less attention. The productivity studies primarily used production-system indicators such as throughput, production output, cycle time, and waiting time. These measures differ from conventional field productivity measures such as installed quantity per labor hour and labor utilization based on direct work, support work, and idle time.

Table 10: Project Performance Outcomes Reported in Prior Multiskilling Studies

Project outcome	Number of studies	How it was measured	Finding
Schedule	16 (27%)	Project duration, construction duration, completion time, cycle time, makespan, or production duration	Reductions ranged from about 2% to 58%
Cost	11 (19%)	Labor cost, cost price, workforce allocation cost, production cost, or project cost	Savings ranged from about 0.3% to 58%; increases ranged from about 4% to 26%
Workforce Requirements	6 (10%)	Workforce requirement, worker demand, labor allocation, or labor deficit	Reductions ranged from about 2% to 53%
Productivity	4 (7%)	Daily throughput, production output, cycle time, or waiting time	Improvements ranged from about 2% to 77%

Note: Counts may overlap because some studies reported more than one project performance outcome.

SCHEDULE

Schedule was the most frequently measured project-performance outcome, appearing in 16 studies. Ten studies examined project, construction, completion, or simulated project duration. The remaining six examined cycle time, production completion time, makespan, or production duration, often in off-site, prefabrication, or factory-based settings.

UNDERSTANDING THE SCHEDULE MEASURES

The schedule studies did not all measure the same type of time impact:

- **Project, construction, completion, or simulated project duration:** time required to complete a project, modeled project, or project case.
- **Cycle time, production completion time, makespan, or production duration:** time required to complete a production sequence, often in off-site, prefabrication, or factory settings.

Table 11: Schedule Findings Reported in Prior Multiskilling Studies

Study ID	Schedule measure	Basis for result	Schedule Reduction	Country
Study 2	Project duration	Scheduling algorithm using published benchmark/project scheduling data	4% to 29%	Not specified; authors based in Canada, Egypt, and Saudi Arabia
Study 17	Cycle time	Production-management simulation evaluating a combined intervention that included multiskilling	About 58%*	Not specified; authors based in Israel
Study 20	Construction duration	Simulation/modeling based on construction-firm project data	20%	Estonia
Study 23	Project duration	Heuristic scheduling model using multiskilled resource scheduling cases	18% to 39%	Not specified; authors based in Thailand
Study 25	Completion time	Modeled construction program comprising 10 hypothetical projects	About 6%	Not specified; authors based in Colombia and the United States
Study 26	Completion time	Off-site production data used to parameterize and validate simulation models	2% to 44%	Australia
Study 28	Project duration	Crew-composition optimization model applied to a residential building case	27%*	Australia
Study 35	Simulated project duration	Agent-based regional industry simulation	8% to 39%*	United States
Study 37	Makespan	Prefabrication factory data used in a resource allocation model	26% to 41%	Australia
Study 38	Makespan	Off-site production data analyzed using hybrid optimization and MCDM	17% to 53%	Australia
Study 45	Makespan	Off-site factory case analyzed using integer linear optimization	30% to 33%	Australia
Study 49	Production duration	Off-site shop-floor data used in a digital twin simulation model	40%*	Canada
Study 50	Project completion time	Case study using optimization	5%*	China
Study 52	Project duration	Bridge project case analyzed using hybrid quantum optimization	24%*	China
Study 55	Project duration	Mathematical model incorporating workforce dexterity improvement	18%*	Not specified; authors based in Iran
Study 56	Project completion time	Railway bridge case analyzed using a fuzzy optimization model	14%*	Iran

*Note: The reported finding reflects a study-specific comparison in which multiskilling was combined with another factor or was not evaluated as an isolated effect. Additional details are provided in Appendix A. For example, the reduction reported in Study 50 resulted from adding learning effects within a multiskilled staff-assignment model; both comparison cases used multiskilled staff.

COST

Eleven studies reported cost outcomes associated with multiskilling. The measures included labor cost, cost price, workforce allocation cost, production cost, and total project cost.

Cost was the project performance outcome for which both reductions and increases were reported. Cost savings ranged from approximately 0.3% to 58%, while increases ranged from approximately 4% to 26%. The direction and size of the results depended on the multiskilling strategy, workforce arrangement, study setting, and type of cost measure.

UNDERSTANDING THE COST MEASURES

The cost studies did not all measure the same type of financial impact:

- **Labor cost:** the cost of employing workers, including wages or modeled labor expenditures under different workforce arrangements.
- **Cost price:** the calculated cost of completing the work under a particular workforce configuration.
- **Workforce-allocation cost:** the cost of assigning and deploying workers across tasks, projects, or work periods.
- **Production cost:** the cost of producing components or units, which may include labor, inventory, outsourcing, production switching, and other operating costs.
- **Project cost:** the overall cost of completing a project or modeled project case, rather than labor or production cost alone.

COST FINDINGS IN BRIEF

11	0.3–58%	4–26%
studies reported cost outcomes	range of reported cost savings	range of reported cost increases

Table 12: Cost Findings Reported in Prior Multiskilling Studies

Study ID	Cost measure	Basis for result	Finding	Country
Study 1	Labor cost	Estimates and multiskilling scenarios for a theoretical model project	Savings from 3% to 20%	United States
Study 5	Labor cost	Genetic algorithm model using practical/hypothetical labor allocation examples	About 4% increase	Not specified; authors based in China (Hong Kong)
Study 14	Labor cost	Construction Industry Institute (CII) model plant labor-demand profile and optimal workforce investment model	0.3% savings*	United States
Study 20	Cost price	Simulation/modeling based on a construction firm context	3% reduction	Estonia
Study 22	Labor cost	Finishing-work assignment example from a prior study analyzed using a multiskilled workforce-assignment model	About 2% to 4% lower cost	Not specified; authors based in Jordan and the United States
Study 25	Labor cost	Modeled construction program comprising 10 hypothetical projects	About 2% reduction	Not specified; authors based in Colombia and the United States
Study 37	Labor cost	Prefabrication factory data used in a resource allocation model	25% to 58% reduction under some strategies and variability conditions; 17% to 26% increase under others	Australia
Study 41	Workforce allocation cost	Multiproject workforce-assignment model using standard RCPSP cases and assumed human-resource data	9% decrease*	Not specified; authors based in Iran
Study 49	Production cost	Off-site shop-floor data used in a digital twin simulation model	25% reduction*	Canada
Study 56	Project cost	Railway bridge case analyzed using a fuzzy optimization model	24% reduction*	Iran
Study 59	Production cost	Optimization and computational experiments using operational records from a precast-component manufacturer	7% to 12% reduction*	China

*Note: The reported finding reflects a study-specific comparison in which multiskilling was combined with another factor or was not evaluated as an isolated effect. Additional details are provided in Appendix A. For example, the savings in Study 14 came from an integrated workforce-investment model involving training, hiring, and allocation decisions.

The studies used different cost measures, which affects how the reported percentages are compared. Some studies examined craft labor cost, while others measured workforce-allocation cost, production cost, cost price, or total project cost. A reduction in labor cost does not necessarily produce an equivalent reduction in total production or project cost. Each percentage should therefore be interpreted in relation to the cost category measured.

Country context and data source also shaped the basis of the reported findings. The U.S. evidence came primarily from related analyses of a theoretical project, referred to as a "model plant," for which construction companies in the 1990s provided cost estimates and resource-loaded schedules for a hypothetical industrial plant. Studies from Australia, Canada, China, Estonia, and Iran represented different labor markets, trade practices, and project delivery conditions. This leaves limited current U.S. field evidence on the cost effects of multiskilling.

WORKFORCE REQUIREMENTS

Six studies examined the effect of multiskilling on workforce requirements. Five focused on worker or crew counts, including required workforce, worker requirements, crew requirements, and the number of workers allocated. The sixth examined labor deficit, defined as the gap between the labor required and the labor available under constrained conditions. Reported reductions ranged from about 2% to 53%.

Table 13: Workforce Requirement Findings Reported in Prior Multiskilling Studies

Study ID	Workforce measure	Basis for result	Finding	Country
Study 1	Required workforce	CII model plant using labor estimates and multiskilling scenarios	18% to 35% reduction	United States
Study 22	Required workforce	Finishing-work assignment example from a prior study, analyzed using a multiskilled workforce-assignment model	About 2% to 4% fewer workers*	Not specified; authors based in Jordan and the United States
Study 27	Worker requirement	Scheduling framework using repetitive project data	28% to 53% reduction	Not specified; authors based in India
Study 31	Crew requirement	Repetitive-project crew-routing optimization using project data	About 36% reduction*	Not specified; authors based in Egypt
Study 41	Number of allocated workers	Multiproject workforce-assignment model using standard RCPSP cases and assumed human-resource data	Up to 40% reduction*	Not specified; authors based in Iran
Study 44	Labor deficit	Agent-based simulation of construction labor availability under COVID-19 disruption scenarios	Labor deficit reduced from 33% to 17%, approximately 50% reduction	Not specified; author based in Chile

*Note: The reported finding reflects a study-specific comparison in which multiskilling was combined with another factor or was not evaluated as an isolated effect. Additional details are provided in Appendix A. For example, the reduction in Study 41 came from the complete multiproject workforce-assignment model and was not isolated as a multiskilling effect.

All six studies reported reductions in workforce requirements, worker or crew allocation, or labor deficit under at least one arrangement examined. In five studies, the arrangements examined resulted in fewer workers or crews being required or allocated. In the sixth, multiskilling reduced the gap between labor demand and available labor. These findings indicate that workers with broader skill coverage can perform a wider range of required work and give project teams greater flexibility in assigning available labor.

The findings were derived primarily from model-based analyses rather than observed staffing changes on active projects. The U.S. finding came from a Construction Industry Institute (CII) model-plant analysis using labor estimates and multiskilling scenarios. The remaining studies used scheduling, workforce-assignment, crew-routing, or agent-based simulation models, with some study contexts not tied to a stated project or data location. The reported reductions therefore represent estimated effects under the conditions examined rather than staffing reductions verified through workforce records from completed projects.

Key Finding for Workforce Outcome: Multiskilling reduced modeled workforce requirements and labor deficits by allowing available workers to cover a broader range of work. The reported effects were derived mainly from analytical models rather than staffing records from implemented multiskilling arrangements on current onsite projects.

PRODUCTIVITY

Productivity received less attention than cost or schedule, with four studies reporting productivity-related outcomes (see Table 14). None reported conventional labor productivity measures, such as output per labor hour, labor hours per unit of work, or similar production rates that account for labor input. Instead, they used production-flow indicators: throughput (output per period of time, such as units produced per day), waiting time, and cycle time. These measures show how multiskilling affected production output, flow continuity, and delays under the tested conditions and represent different dimensions of production performance.

Reported improvements ranged from about 2% to 77%. The percentages are not directly comparable, however, because the studies measured different aspects of production performance: a gain in throughput, a reduction in waiting time, and a reduction in cycle time represent different changes and cannot be read as a single productivity effect.

Table 14: Productivity-Related Findings Reported in Prior Multiskilling Studies

Study ID	Productivity measure	Basis for result	Finding	Country
Study 17	Throughput rate	Production-management simulation evaluating a combined intervention that included multiskilling	Throughput increased by about 54%*	Not specified; authors based in Israel
Study 26	Throughput rate	Off-site production data used to parameterize and validate simulation models	Throughput rate improved by 2% to 77%	Australia
Study 30	Daily throughput	Construction case-project performance data used in a discrete-event simulation of job assignment strategies	Daily throughput improved by 28%	Australia
Study 49	Waiting time and cycle time	Off-site shop-floor data used in a digital twin simulation model	Average waiting time reduced by 62%; average cycle time reduced by 37%*	Canada

*Note: The reported finding reflects a study-specific comparison in which multiskilling was combined with another factor or was not evaluated as an isolated effect. Additional details are provided in Appendix A. For example, digital-twin intervention and multiskilled-worker reassignment were evaluated together for Study 49.

The findings indicate improved production flow under the multiskilling arrangements examined. Higher throughput represents greater production output over a given period, while shorter waiting and cycle times indicate fewer delays and faster movement through the production process. These measures capture aspects of production flow but do not capture other dimensions of labor performance, such as production relative to labor input or how worker time is distributed across work activities.

The research was limited in scope. Two studies examined off-site or shop-floor production, while one used data from an onsite residential project within a simulation model. The fourth evaluated productivity-related outcomes as part of a broader production-management intervention that included multiskilling. All four relied on simulation-based analysis, although actual project or production data informed several of the analyses. The reported improvements therefore resulted from the scenarios or interventions tested rather than direct field comparisons of multiskilled and single-skilled crews working on active jobsites.

Key Finding for Productivity Outcome: Multiskilling was associated with higher throughput and reductions in waiting and cycle times in the studies reviewed. These findings support improved production flow, but direct onsite evidence examining multiskilling using other labor-performance measures, including production relative to labor input and work-time utilization, remains limited.

Worker Development, Training, and Strategy

Twenty-one studies discussed how multiskilling may affect workers, including pay, employment duration, job security, skill development, employability, and motivation to acquire additional skills. The studies considered both the benefits workers may receive from multiskilling and the factors that may encourage them to develop broader skill sets (see **Table 15**).

The type of evidence varied across the studies. Surveys and interviews captured worker attitudes, motivations, training needs, and receptiveness to broader work responsibilities. Other studies examined company training practices, assessed technical or management competencies, or used analytical models to estimate changes in employment duration, wages, and salary. Several studies discussed potential benefits, such as employability, career development, job satisfaction, workload balance, and greater workforce flexibility, without measuring these outcomes directly.

Training was commonly described as occurring through work experience, sometimes supplemented by classroom instruction. Some studies also extended multiskilling beyond craft tasks to include broader technical and management capabilities. These findings indicate that workforce development involved not only increasing the number of skills held by workers, but also developing sufficient competency to apply those skills effectively. Some studies suggested that the additional value of multiskilling may diminish after workers become competent in approximately two or three crafts.

Worker motivation was closely connected to the perceived value of acquiring another skill. One of the clearest sources of direct evidence comes from Carley et al. (2003), who surveyed 721 nonunion craft workers in U.S. industrial construction. The leading reasons workers gave for learning another trade were higher pay, interest in the trade, and continuous employment. In the survey data, workers with broader skill sets did earn slightly higher hourly wages, although the gain diminished with each added trade. The expected employment benefit, however, largely failed to appear: holding more trades was only weakly related to more continuous employment. Other studies similarly connected worker receptiveness to compensation, learning opportunities, career advancement, job security, professional interest, and the practical usefulness of the additional skill.

At the organizational level, multiskilling was presented as a strategy for developing a more adaptable workforce and preparing workers for changing project demands and broader responsibilities. However, direct evidence of sustained competency development, long-term career progression, and employment stability remained limited.

The leading reasons workers gave for learning another trade were higher pay, interest in the trade, and continuous employment.

Table 15: Workforce Development and Worker Benefit Findings Reported in Prior Multiskilling Studies

Area	General finding
Training and competency development	Multiskilling involved developing broader craft, technical, and management capabilities. Training was commonly provided through work experience and was sometimes supplemented by classroom instruction
Motivation to gain additional skills	Higher pay, interest in another trade, continuous employment, competency development, professional interest, prestige, and job security were reported as reasons for gaining additional skills
Worker receptiveness	Workers appeared more receptive when additional skills were useful in practice and linked to compensation, training, career advancement, or broader responsibilities
Wages and earning potential	Broader skill sets were connected to higher hourly wages, wage increases, or skill-based wage structures in several studies
Employment duration and continuity	Some studies estimated longer employment within a project, while direct survey evidence found only a weak relationship between multiskilling and continuous employment
Skill development and career progression	Multiskilling was discussed as a way to improve employability, expand career options, and support technical or management skill development

QUANTIFIED WORKER OUTCOMES

Although workforce development and worker benefits were discussed across 21 studies, only four reported quantified worker outcomes.

Table 16: Quantified Worker Outcomes Reported in Prior Multiskilling Studies

Study ID	Worker-focused measure	Basis for result	Finding	Country
Study 1	Employment duration	CII model plant and multiskilling strategy comparison	Employment duration increased by about 18% to 47%	United States
Study 25	Labor stability	Modeled construction-program scheduling and workforce allocation	Single-skilled workers had 33.3% higher maximal labor fluctuation and 14.3% higher total labor fluctuation than multiskilled workers; multiskilling also reduced firing events	Not specified; authors based in Colombia and the United States
Study 27	Employment duration	Repetitive construction project case and scheduling framework	Employment duration increased by 67% to 179% for the shuttering–carpenter arrangement and by 6% to 51% for the barbender–mason arrangement, depending on the comparison trade	Not specified; authors based in India
Study 38	Salary	Off-site production data analyzed using hybrid optimization and MCDM	Modeled salary increased by about 4% to 37% compared with the no-cross-training baseline	Australia

The quantified findings indicate potential worker benefits related to longer project employment, greater labor stability, and higher salary potential. Longer employment duration meant that workers remained part of the project workforce for a greater portion of the work, while the labor-stability findings reflected reduced workforce fluctuations and firing events. The salary finding indicated a possible financial benefit from broader skill sets. These results support the wider discussion of pay and steadier work opportunities as benefits workers may associate with multiskilling.

The findings were based mainly on model-plant, scheduling, and optimization analyses rather than observed worker, employment, or project records from active projects. The reported changes therefore represented estimated worker benefits under the conditions examined.

For the employment-duration findings, longer employment within one project is not equivalent to long-term job security. The studies measured the length of time workers remained assigned within a project, production system, or workforce plan. They did not establish continued employment across projects, long-term retention by an employer, or reduced unemployment between projects.

Key Worker Benefits Takeaway: Workers were most commonly motivated by higher pay, interest in additional trades, learning opportunities, more continuous employment, and broader career prospects. The quantified studies also estimated longer project employment, greater labor stability, and higher salary potential, but direct evidence of long-term employment stability and sustained financial benefits remains limited.

Implementation and Adoption of Multiskilling

Fourteen studies examined how multiskilling was introduced and used in construction and construction-related settings. The evidence came from company interviews, site visits, worker and employer surveys, demonstration projects, implementation frameworks, and literature reviews. Most studies focused on the organizational and workforce conditions needed to put multiskilling into practice rather than on measurable project outcomes.

There was no single approach to implementation. Companies had to decide where multiskilling was suitable, which skills should be combined, which workers required additional training, how workers would be assigned, and how broader responsibilities would be recognized and compensated. These decisions were influenced by project size, the amount of specialized work, training capacity, workforce stability, labor arrangements, certification requirements, and prior experience with multiskilled workers.

The main reasons for adopting multiskilling included greater workforce flexibility, retention and development of experienced workers, competitive advantage, service customization, perceived productivity benefits, and the ability to respond to changing work demands. In some settings, regulatory requirements and financial incentives also encouraged adoption. Multiskilling was often used alongside specialist labor and subcontracting rather than as a complete replacement for trade specialization.

Worker acceptance depended partly on how the strategy was introduced. Workers were generally more receptive when the purpose was clearly explained and when additional skills or responsibilities were connected to training, compensation, career development, or continued employment opportunities. Employee involvement, management support, and coordination with unions or other affected parties were also relevant when implementation changed established roles or trade boundaries.

Common challenges included training and compensation costs, traditional craft or professional boundaries, resistance to changing established practices, uncertainty over responsibility for training, limited formal training opportunities, certification requirements, and difficulty applying multiskilling to highly specialized or task-specific work. The significance of these challenges differed by company, occupation, labor market, and regulatory setting.

Table 17: Implementation and Adoption Findings Reported in Prior Multiskilling Studies

Area	General finding
Implementation planning	Companies needed to determine where multiskilling was suitable, which skills should be combined, which workers should be trained, and how workers would be assigned.
Adoption drivers	Workforce flexibility, worker development and retention, competitive advantage, service customization, perceived productivity benefits, and regulatory or financial incentives encouraged adoption.
Training and skill assessment	Implementation required an understanding of workers' existing capabilities, additional training needs, and readiness to perform broader work responsibilities.
Worker acceptance	Workers were generally more receptive when multiskilling was clearly explained and connected to compensation, training, career development, or continued employment opportunities.
Organizational support	Management commitment, workforce planning, suitable team and supervisory arrangements, and clear procedures for using multiskilled workers supported implementation.
Compensation and recognition	Broader skills and responsibilities needed to be recognized through wage progression, advancement opportunities, or other incentives.
Stakeholder coordination	Coordination with workers, unions, subcontractors, and other affected parties was relevant when implementation changed established roles or work boundaries.
Common challenges	Training and compensation costs, established work boundaries, resistance to change, certification requirements, limited training opportunities, and specialized-work demands constrained adoption.
Selective use	Multiskilling was often used alongside specialist labor and subcontracting rather than replacing specialized trades entirely.

Training workers in additional skills was only one part of implementation. Companies also needed to connect worker capabilities with project requirements, workforce-planning systems, compensation practices, certification standards, and existing labor arrangements. The reviewed studies did not identify one approach that would work across all companies and project types.

Most evidence came from company practices, worker perceptions, demonstration projects, and proposed frameworks. Few studies followed implementation over time or measured how specific adoption practices affected later project or worker outcomes.

Implementation and Adoption Takeaway: Multiskilling appeared most feasible when it addressed a clear workforce or project need and was supported through training, compensation, planning, and coordination with affected parties. Training and certification costs, established work boundaries, resistance to change, and specialized work requirements remained common challenges. Multiskilling was generally treated as a complement to specialist labor rather than a full replacement for trade specialization.

Skill Combinations in Multiskilling

The reviewed studies examined multiskilling at both the worker and crew levels. Some classified workers by the number of skills they could perform, while others examined how workers were trained, hired, grouped, or reassigned across trades, tasks, work processes, and production workstations. The structure of multiskilling differed between off-site production settings and conventional onsite construction.

WORKFORCE TERMS AND CLASSIFICATIONS

The studies used several classifications to distinguish workers and crews according to the number or range of skills they could perform (see Table 18). The most common distinction was between single-skilled, dual-skilled, and multiskilled workers. Some studies also treated multiskilling as a crew-level arrangement in which workers within the crew collectively performed work that would otherwise be assigned to separate trades or specialized crews.

Table 18: Workforce Classifications Used in Prior Multiskilling Studies

Term	Meaning in the reviewed studies
Single-skilled worker	A worker assigned to one primary trade, skill area, task category, or workstation. Single-skilled workers were commonly used as the comparison group.
Dual-skilled worker	A worker capable of performing work in two distinct skill areas, generally a primary skill and one additional skill.
Multiskilled worker	A worker capable of performing work across two or more distinct skills, trades, tasks, or workstations. The number of skills was not always specified.
Multiskilled crew or team	A crew organized to complete more than one distinct type of work, with workers capable of covering or being reassigned across the crew's tasks.

MULTISKILLING IN OFF-SITE AND PREFABRICATION STUDIES

In off-site construction, building components, assemblies, or modules are produced in a factory or another controlled location before being transported to the project site (see Table 19). Production in the reviewed studies was generally organized as a sequence of workstations, with workers assigned to specific operations such as mechanical work, plumbing, carpentry, electrical work, waterproofing, glazing, and painting.

Multiskilling was used to allow workers to support more than one workstation when workloads became uneven or bottlenecks developed. The studies examined two broad approaches: training existing workers to cover additional workstations and hiring workers who already possessed multiple skills. Single-skilled arrangements, in which workers remained at their primary workstations, were commonly used as the comparison case.

Table 19: Multiskilling Arrangements Examined in Off-Site and Prefabrication Studies

Approach	Arrangement	Meaning in the reviewed studies
Training existing workers	Chaining	Workers were trained to operate at a secondary workstation located next to their primary station
	Direct capacity balancing	Selected workers were trained to support overutilized workstations or stations with recurring production bottlenecks
	Upstream training	Workers gained the skills needed to support stations located earlier in the production sequence
	Downstream training	Workers gained the skills needed to support stations located later in the production sequence
	Full cross-training	Existing workers were trained to operate across most or all workstations in the production process
Hiring multiskilled workers	Hiring a multiskilled crew	A small number of cross-trained workers were hired to move among bottleneck workstations and provide support where needed
	Hiring dual-skilled workers	Workers were hired with two existing skills that allowed them to support more than one workstation or production area
	Hiring four-skilled workers	Workers were hired with capabilities covering four skill or production areas
	Hiring four-skill helpers	Helper-level workers were hired with capabilities covering four skill or production areas.

The training arrangements differed in the number and location of the workstations that workers could support. Some targeted an adjacent, upstream, downstream, or high-demand workstation, while full cross-training allowed workers to move across most of the production process. Hiring strategies introduced workers who already possessed dual or broader skill capabilities. In both approaches, multiskilling was used to redirect labor toward workstations experiencing uneven workloads, capacity constraints, or recurring bottlenecks.

MULTISKILLING STRATEGIES IN ONSITE CONSTRUCTION

Onsite studies structured multiskilling by expanding the number of skills held by individual workers, combining several trades into broader workforce groups, or organizing crews to perform multiple types of work. The main arrangements examined in the reviewed studies are summarized in Table 20.

Table 20: Multiskilling Strategies Used in Onsite Construction Studies

Strategy	Meaning in the reviewed studies
Single-skill strategy	Each worker remained assigned to one primary trade or skill area. This strategy was commonly used as a comparison case
Dual-skill strategy	A worker could perform work associated with two distinct trades or skill areas
Four skills strategy	Project trades were consolidated into four broad groups: civil/structural, general support, mechanical, and electrical
Four skills-helper strategy	The same four broad groups were used, but helpers from all trades were pooled into the general support group. Journeymen and foremen remained within the group associated with their original trade
Multiskilled crew or team	A crew was organized so that workers could cover or be reassigned across multiple types of work that might otherwise be assigned to separate workers or trade crews.

These strategies described the structure of the workforce but did not always identify the specific trades combined. A dual-skill strategy, for example, could include several possible trade pairings, while a four-skill strategy consolidated multiple trades into broader civil/structural, general support, mechanical, and electrical groups.

TRADE AND SKILL COMBINATIONS REPORTED IN PRIOR STUDIES

Some studies identified specific trade or skill combinations rather than describing only the number of skills held by a worker or the broader workforce arrangement. Of the eight studies that examined skill configurations or combinations, five reported specific dual-trade or skill pairings. Table 21 presents the named dual-trade and skill pairings and identifies the studies in which each combination appeared.

Table 21: Trade and Skill Combinations Reported in Prior Studies

Trade and Skill Combinations Reported in Prior Studies

Named dual-trade and skill pairings; letter codes identify the studies in which each combination appeared

Trade	CP	CF	EL	RI	WD	RG	PF	BM	SB	PT	IN	SI	EO	DW	ES	FL	SHM	RF	IW-C	HVAC
CP	—																			
CF	B, D, E	—																		
EL	E	E	—																	
IT			B																	
MW		A																		
RI	B, D	B, C, D		—																
WD	E	E	E		—															
RG						—														
PF	A, E	E	E		E	D	—													
BM	E		E		B, E	B, D	B, D, E	—												
SB	B, D							D	—											
PT	E	E	E		E		E	E		—										
IN			A						B, D		—									
SI				A		B, D						—								
IF			B								B									
EO	E	E	E		E	A, B, D	E	E		A, E		B	—							
GL					A															
DW	E	E	E		E		E	E		E			E	—						
ES	E		E		E		E	E		E			E		—					
FL	E	E	E		E		E	E		E			E	E	E	—				
SHM	E	E	E		E		E	E		E			E	E		E	—			
RF	E	B, E	E		E		E	E		B, E			E	E	E	E	E	—		
IW-C	E	E	E		E		E	E		E			E	E	E	E	E	E	—	
HVAC	E	E	E		E		E	E		E			E	E	E	E	E	E	E	—

Study key: A Burleson et al., 1998 · **B** Wang et al., 2009 · **C** Pandey and Maheswari, 2015 · **D** Albattah et al., 2022 · **E** Oh et al., 2023

Each pairing is shown once because the order of the trades does not indicate a primary or additional skill. Only named dual-skill combinations are included.

Note: Letter codes identify the studies associated with each combination. Each pairing is shown once because the order of the trades does not indicate a primary or additional skill. Only named dual-skill combinations are included. Broader trade groupings were not converted into individual trade pairs.

TRADE-CODE KEY

CP = Carpenter; CF = Concrete finisher (including Mason); EL = Electrician; IT = Instrument technician; MW = Millwright; RI = Reinforcing ironworker; WD = Welder; RG = Rigger; PF = Pipefitter; BM = Boilermaker; SB = Scaffold builder; PT = Painter; IN = Insulator; SI = Structural ironworker; IF = Instrument fitter; EO = Equipment operator (Crane Operator, etc.); GL = General laborer; DW = Drywaller (including ceiling tile installers and tapers); ES = Elevator and escalator installers and repairers; FL = Floor installers; SHM = Sheet metal workers; RF = Roofer; IW-C = Both structural and reinforcing iron workers; HVAC = Heating, ventilation, and air conditioning.

The findings show that prior studies did not use a single approach to structuring multiskilling. Off-site studies generally focused on workers' ability to move among production workstations, while onsite studies focused more on trade expansion, broader trade groupings, and multiskilled crews. Many studies classified workers according to the number of skills they possessed without identifying the specific trades or tasks combined. Consequently, the literature provides more information about the breadth of multiskilling than about which particular skill combinations are most practical or effective in construction.

Skill Combination Takeaway: Multiskilling was structured differently across onsite and off-site settings. Off-site studies emphasized flexibility across production workstations, while onsite studies emphasized dual-skilling, broader trade groupings, and multiskilled crews. However, many studies did not identify the specific trades or skills combined, limiting conclusions about which combinations are most suitable for construction practice.

Interpretation of Findings

The reviewed literature generally presented multiskilling favorably, but the findings varied across performance outcomes, workforce arrangements, and research settings. The evidence therefore suggests that multiskilling may be a useful workforce strategy, but not one that will produce the same result under all project conditions.

OVERALL DIRECTION OF THE FINDINGS

Each study was classified based on the general direction of its findings and discussion of multiskilling (see Table 22). These classifications reflect the general view of multiskilling presented in each study. They do not indicate how frequently multiskilling will produce favorable results on construction projects.

Table 22: Overall Direction of Findings in Reviewed Multiskilling Studies

Direction of findings	Number of studies	Percentage	Meaning
Fully Advantageous	42	71%	The study discussed multiskilling as being a valuable strategy or emphasized its potential benefits.
Mixed or conditional	14	24%	The findings varied by outcome, multiskilling strategy, or study condition.
No clear direction	3	5%	The study did not discuss a clearly favorable or unfavorable conclusion.
Fully Disadvantageous	0	0%	No study concluded that multiskilling was disadvantageous across any of the outcomes or conditions examined.

The vast majority of studies (56 of 59) discussed multiskilling as being a valuable strategy or emphasized its potential benefits. 42 studies discussed only advantageous impacts of multiskilling. 14 studies found a mixture of both advantageous and disadvantageous impacts depending upon the conditions examined, while cost findings moved in both directions; for example, in several off-site studies, one multiskilling arrangement reduced cost while another increased it. The results therefore depended partly on the conditions, data sources, and methods of analysis under which multiskilling was examined.

IMPLICATIONS FOR CONSTRUCTION PRACTICE

Much of the quantified evidence came from simulations, optimization models, scheduling analyses, and scenario comparisons. Some studies used data from actual projects, firms, or production facilities, but the reported effects were often calculated through models rather than measured after implementation. The reported percentages therefore reflect the assumptions and workforce arrangements examined in each study rather than the result that should be expected on a typical construction project.

A considerable share of the quantified evidence came from off-site production, prefabrication facilities, model plants, benchmark cases, or hypothetical project scenarios. These settings provide useful information about labor assignment and production flow, but their operating conditions differ from conventional onsite construction. Active jobsites may involve changing work areas, subcontracting arrangements, trade boundaries, access constraints, weather, and less predictable work availability. Findings from more controlled settings may therefore not transfer directly to onsite construction.

Worker benefits were also discussed more often than they were measured. Studies described possible benefits such as higher pay, additional training, broader career opportunities, and longer employment within a project, but these outcomes were discussed more frequently than they were measured. Longer employment on one project also does not demonstrate continued employment across projects or long-term job security.

Industry takeaway: The literature generally presents multiskilling positively, but its reported effects on project performance were not consistent across all workforce strategies and settings. Most quantified findings came from models or controlled production environments rather than direct measurement on active construction projects, and evidence from U.S. projects was particularly limited.

SECTION 6

Gaps and Recommendations for Future Research

The review identified six gaps in the existing multiskilling literature. The gaps span the research settings represented, the methods used to determine and measure multiskilling effects, the outcomes examined, and the reporting of workforce arrangements and skill combinations. Table 23 summarizes the gaps.

Table 23: Summary of Research Gaps

Research gap	Description
Limited field data from onsite construction projects	Few studies used data from onsite construction projects, and none examined project-performance effects on an active U.S. onsite project
Reliance on model-based performance findings	Quantified effects were largely generated through analytical models rather than measured after implemented multiskilling arrangements on active construction projects
Limited onsite head-to-head comparisons between multiskilling and single-skilling	Few studies directly compared multiskilled and single-skilled labor using data from onsite construction projects under comparable field conditions
Inconsistent measurement of project performance outcomes	Studies used different measures, scopes, and units of analysis, limiting direct comparison of reported effects
Limited coverage of productivity and workforce requirements	Productivity and workforce requirements received less attention than schedule and cost
Limited reporting of skill combinations	Most studies did not clearly identify the skill combinations or crew configurations examined

Limited Field Data from Onsite Construction Projects

A major gap is the limited use of data from field or onsite construction projects. Although 26 of the 59 studies quantified project performance outcomes, only 7 studies used any form of data from onsite construction projects. These studies included both data collected directly from projects and previously published data from actual onsite project cases. As shown in Table 24, reported project locations included Australia, China, and Iran, while the locations of some projects were not specified; none involved a project located in the United States. The study year is also listed because the publication timeline indicates that the actual project measurements were conducted prior to the year of publication; therefore, the studies are likely to be based on projects constructed before their respective publication years (during a timeframe between 2015 and 2025 or earlier).

Table 24: Studies Using Onsite Construction Project Data

Study ID	Number of projects	Project type	Location	Publication year
Study 27	1 project	Repetitive mass-housing project; project data included completed dwelling units and a utility building	Not specified; authors based in India	2015
Study 28 and Study 30	1 project	Residential building; three-story structure with an underground car park	Australia	2016 and 2017
Study 31	1 project	Sewage-pipeline project	Not specified; authors based in Egypt	2017
Study 50	1 project	Hospital building project	China	2023
Study 52	1 project	Bridge project	China	2023
Study 56	1 project	Railway bridge project	Iran	2024

The 7 studies represented six distinct project cases because Studies 28 and 30 used the same Australian residential project. The cases also covered a limited range of project types and geographic locations, so the findings do not show how multiskilling may perform across a broader range of building, infrastructure, and industrial construction settings.

The U.S. context was not represented among the onsite projects. U.S.-based studies used model plants, expert staffing plans, survey data, certification records, organizational or project records, and industry examples. However, none used data from an active U.S. onsite construction project to examine effects on cost, schedule, productivity, or workforce requirements. This leaves limited information on how multiskilling performs under current U.S. jobsite conditions.

Future research should include more onsite construction projects and observations across crews, activities, and project phases. Studies covering different project types, trades, geographic regions, and labor conditions would provide a broader basis for assessing multiskilling. Research on active U.S. projects is especially needed because this setting was not represented in the reviewed onsite project cases.

Reliance on Model-Based Performance Findings

A second gap concerns how the project performance effects of multiskilling were determined. In this review, the reported percentage effects in the 26 project-performance studies were derived through simulation, optimization, scheduling analysis, or scenario-based comparison. Some studies used project, company, or production data as model inputs, while others used a single model project (based on a theoretical industrial plant), benchmark cases, or assumed scenarios. Thus, even when actual project or company data were used, the reported effects were calculated through analytical models rather than measured from multiskilling arrangements implemented on active construction projects.

Table 25: Basis for Project-Performance Findings in Prior Multiskilling Studies

Basis for findings	Study IDs	Number of studies	Description
Actual onsite construction project cases	Studies 27, 28, 30, 31, 50, 52, and 56	7	Used identifiable onsite construction projects, but the reported effects were derived through scheduling, optimization, or other model-based analysis.
Construction firm or project records	Studies 17 and 20	2	Used construction-firm or project records as inputs to simulation or optimization models, rather than directly measuring performance after implementation.
Project-market or regional simulation inputs	Study 35	1	Used residential project and regional construction-market data to simulate multiskilling effects at the project and market levels.
CII model plant or expert-developed staffing model	Studies 1 and 14	2	Used model-plant data, labor-demand profiles, expert-developed staffing plans, or resource-loaded schedules to estimate multiskilling effects.
Off-site, prefabrication, or shop-floor production data	Studies 26, 37, 38, 45, 49, and 59	6	Used off-site production or prefabrication data to evaluate multiskilling strategies in controlled production settings.
Published benchmark, hypothetical, or assumed scenarios	Studies 2, 5, 22, 23, 25, 41, 44, and 55	8	Used benchmark problems, assumed project scenarios, or researcher-defined inputs to estimate performance effects.

In this review, simulation studies represent a project, production system, or labor market condition and test how changes in labor assignment may affect outcomes. Specifically,

- Optimization studies identified the preferred labor assignment, crew composition, schedule, or workforce strategy under defined constraints.
- Scheduling studies examined how workforce assignments and resource constraints affected activity sequencing, project duration, or production completion time.
- Scenario-based studies compared alternative labor-use strategies under assumed or predefined conditions.

These approaches are useful for evaluating different workforce arrangements, but their findings depend on the assumptions, constraints, and inputs used in each analysis. The literature therefore provides more information on the potential effects of multiskilling than on the performance achieved through implementation on active construction projects.

An early example is the Construction Industry Institute (CII) study conducted in 1998, which examined a model petrochemical plant. The study became one of the foundational examples in construction multiskilling research and was later used or referenced in related studies. It estimated the effects of multiskilling using labor-demand profiles, expert-developed staffing plans, and resource-loaded schedules. The study reported potential reductions in labor cost and workforce requirements and an increase in employment duration, but these effects were generated from a model project rather than directly measured on an active construction project.

Future research should complement the existing model-based evidence with measured findings from multiskilling arrangements implemented on active construction projects. Studies should document the workforce strategy, skills involved, and project conditions and assess the resulting changes in cost, schedule, productivity, and workforce requirements. This would provide a stronger basis for evaluating how multiskilling performs under actual construction conditions.

Limited Head-to-Head Comparisons Between Multiskilling and Single-Skilling

Of the 26 studies that quantified project-performance outcomes, 16 compared multiskilling with single-skilling. However, only 3 of these studies used identifiable onsite construction projects. Studies 28 and 30 used the same Australian residential project, meaning that the onsite comparisons represented only two independent project cases.

Table 26: Context of Comparisons Between Multiskilling and Single-Skilling

Comparison context	Study IDs	Number of studies	Onsite project coverage
Onsite construction project cases	Studies 27, 28, and 30	3	Two independent onsite project cases; Studies 28 and 30 used the same project
CII or model-plant cases	Study 1	1	No active onsite project cases
Off-site or prefabrication settings	Studies 26, 37, 38, 45, and 49	5	No onsite construction project cases
Benchmark, hypothetical, firm, regional, or disruption scenarios	Studies 2, 5, 20, 23, 25, 35, and 44	7	No identifiable onsite construction project cases

Although the literature included several comparisons between multiskilling and single-skilling, most were conducted outside active onsite construction. None of the reviewed studies directly compared the performance of multiskilled and single-skilled crews performing comparable work on the same active construction project using the same field performance measures. Most comparisons were based on model plants, factory or prefabrication settings, benchmark cases, company or regional inputs, or assumed project conditions.

To isolate differences associated with the workforce strategy, both crew types should be examined on the same or closely matched work scope, under similar project conditions, and using the same performance measures. Otherwise, reported differences in cost, schedule, productivity, or workforce requirements may also reflect variation in project setting, production environment, work scope, or model assumptions.

A stronger evidence base would come from field-based comparisons of multiskilled and single-skilled crews performing the same or closely matched work on active construction projects. These comparisons should document crew composition, skills involved, work scope, project conditions, and observation period while applying the same performance measures to both workforce strategies.

Inconsistent Measurement of Project Performance Outcomes

Another gap is the limited comparability of the project performance outcomes reported across the reviewed studies. Although the studies examined schedule, cost, productivity, and workforce requirements, they used different measures, units of analysis, and scopes of measurement. As a result, findings grouped under the same outcome category did not always represent the same type of performance change.

Table 27: Differences in Project-Performance Measurement Across Studies

Outcome area	Measures used across studies	Effect on comparison
Schedule	Project duration, construction duration, cycle time, activity duration, completion time, production duration, and makespan	Project-level duration cannot be directly compared with activity-level duration or production-sequence time.
Cost	Labor cost, workforce allocation cost, cost price, production cost, and total project cost	Labor-cost savings do not necessarily represent savings in total production or project cost.
Productivity	Throughput, daily production output, cycle time, and waiting time	These measures capture different aspects of production flow and are not equivalent to a standard labor productivity measure, such as output per labor-hour.
Workforce requirements	Required worker count, worker demand, labor allocation, and labor deficit	Required headcount, assigned workforce, and unmet labor demand represent different workforce conditions.

These differences limit direct comparison of the reported percentages. For example, a reduction in production makespan does not represent the same performance change as a reduction in total project duration. Similarly, a decrease in labor cost does not necessarily indicate a decrease in total project cost. Reported improvements may therefore appear comparable even when they reflect different outcomes, measurement levels, or scopes.

Where possible, future studies examining the same outcome should use comparable measures and clearly distinguish project-level performance from activity- or production-level effects. Greater consistency in the level and scope of measurement would support more reliable comparison and interpretation of findings across studies.

Limited Coverage of Productivity and Workforce Requirements

Schedule and cost were the most frequently examined project performance outcomes, appearing in 16 and 11 studies, respectively. Productivity was measured in only 4 studies, while 6 studies quantified workforce requirements.

These outcomes address important aspects of labor performance. Productivity indicates how labor inputs translate into output or production flow, while workforce requirements reflect staffing needs, labor allocation, and the ability to respond to changes in labor availability. However, the small number of studies provides only a limited basis for assessing how multiskilling affects these outcomes across different project types and workforce conditions.

Additional studies should examine productivity and workforce requirements across a wider range of onsite project settings. Using comparable measures under similar project and work conditions would support a clearer assessment of how multiskilling affects labor efficiency, staffing needs, and workforce deployment.

Limited Reporting of Skill Combinations

Skill combinations or configurations were examined in only 8 of the 59 reviewed studies. This count includes studies that reported specific combinations or broader skill-configuration information as part of a model, strategy, literature or secondary-data analysis, certification or assessment source, or job-advertisement analysis, even when skill combinations were not the study's main research focus. Of the 8 studies, 1 used the CII model plant, 1 examined an onsite construction project, 2 relied on literature or secondary data, 3 used certification or assessment sources, and 1 used job-advertisement data.

Table 28: Studies Reporting Specific Trade or Skill Combinations

Study context or data source	Number of studies	Study IDs
CII model plant	1	Study 1
Onsite construction project	1	Study 27
Literature or secondary data	2	Studies 18 and 36
Certification or assessment sources	3	Studies 21, 43, and 53
Job-advertisement data	1	Study 51

When the review was limited to identifiable project settings, only one publication remained: Study 27, which involved an onsite construction project. That study evaluated proposed combinations through schedule-based scenarios rather than observing multiskilled workers using the combinations in practice. The remaining studies relied on a model plant, literature or secondary data, certification or assessment sources, or job-advertisement data.

Multiskilling is not a single workforce arrangement. Different combinations may involve different tools, training requirements, certifications, work sequences, and opportunities for workers to move between activities. Combining closely related skills may not affect project performance in the same way as combining skills from distinct trades or stages of work. Without identifying the combination examined, it is difficult to determine which form of multiskilling is associated with a reported change in cost, schedule, productivity, labor utilization, or workforce requirements.

The limited reporting also restricts what can be learned about how skill combinations are used in actual construction settings. Certification records and job advertisements can show which skills appear together, but they do not show how workers applied those skills on a project, what activities they performed, or how the combination functioned under field conditions. This project-level information is particularly relevant to contractors and project teams. Future studies should identify workers' primary skill areas, additional skills, and the activities performed under each skill. Where multiple combinations are present, findings should be reported separately by combination rather than grouping all multiskilled workers together. This would provide a stronger basis for determining how different combinations are used and how their effects vary across onsite construction conditions.

Summary

This report reviewed 59 peer-reviewed studies published between 1998 and mid-2026 to examine how multiskilling has been defined, structured, and evaluated in construction research. The literature addressed labor scheduling and assignment, project and production performance, workforce development, implementation, worker outcomes, and skill combinations.

The reviewed studies generally presented multiskilling positively, but the reported effects were not consistent across all outcomes and workforce arrangements. Schedule findings were generally favorable, and the small number of workforce-requirement studies also reported reductions under the conditions examined. Cost findings varied, with some multiskilling strategies reducing cost and others increasing cost, depending on the measure and multiskilling strategy that was investigated. Productivity received limited attention and was assessed mainly through production measures such as throughput, cycle time, and waiting time rather than conventional onsite labor-productivity measures. Possible worker benefits included higher pay, additional skills, broader career opportunities, and longer employment within a project, although few studies measured these outcomes directly.

Most quantified project performance findings were generated through simulation, optimization, scheduling analysis, or scenario-based comparison. Some studies used project, company, factory, or production data as inputs, but the reported effects were still analytically estimated rather than directly measured after multiskilling was implemented. Evidence from active onsite construction projects was limited, and none of the reviewed studies directly measured project performance effects from an implemented multiskilling arrangement on an active U.S. onsite project. Specific skill combinations and crew configurations were also not consistently reported.

The literature therefore supports multiskilling as a potentially useful workforce strategy that can improve labor flexibility and project or production performance when worker capabilities are matched to the needs of the work. However, the findings do not establish one expected effect on cost, schedule, productivity, or workforce requirements. The results depended on the multiskilling arrangement, project or production setting, performance measure, and assumptions used in the analysis. More onsite studies using actual staffing, productivity, cost, and schedule records are needed to examine how different skill combinations and crew arrangements are implemented and how their use affects labor deployment and project performance in the field.

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Appendix A: Summary of Reviewed Studies

This appendix summarizes the 59 peer-reviewed studies included in the review. Each study profile presents the citation, study location, year of publication, research focus, data source, method or approach, multiskilling arrangement examined, key findings, and principal limitations. The study IDs correspond to those used throughout the report.

STUDY 1	
CITATION	Burleson, R. C., Haas, C. T., Tucker, R. L., and Stanley, A. (1998). Multiskilled Labor Utilization Strategies in Construction. Journal of Construction Engineering and Management, 124(6), 480–489.
COUNTRY/REGION	United States
YEAR OF PUBLICATION	1998
STUDY FOCUS	Examined the potential effects of alternative multiskilling strategies on labor cost, workforce requirements, employment duration, and worker earning potential.
STUDY CONTEXT AND DATA SOURCE	CII model petrochemical plant using contractor-developed labor requirements, project schedules, and expert staffing plans.
METHOD/APPROACH	Comparative model analysis of dual-skill, four-skills, four-skills-helper, and theoretical-maximum strategies against a single-skilled baseline using resource-loaded scheduling and an economic labor-cost model.
KEY FINDINGS	Estimated labor-cost savings of 3%–20%. Required workforce reduced by up to 35%. Average employment duration increased by up to 47%. Increased earning potential was identified as a possible worker benefit.
KEY LIMITATION(S)	Findings were derived from a model project and analytically developed staffing plans rather than direct implementation on an active construction project.

STUDY 2	
CITATION	Hegazy, T., Shabeeb, A. K., Elbeltagi, E., and Cheema, T. (2000). Algorithm for Scheduling with Multiskilled Constrained Resources. Journal of Construction Engineering and Management, 126(6), 414–421.
COUNTRY/REGION	Not specified; authors based in Canada, Egypt, Saudi Arabia
YEAR OF PUBLICATION	2000
STUDY FOCUS	Developed a scheduling approach that uses multiskilled resources to reduce delays caused by shortages of constrained labor resources.
STUDY CONTEXT AND DATA SOURCE	A previously published project-scheduling example consisting of 20 activities and 6 constrained resources.
METHOD/APPROACH	Scheduling algorithms and comparative model analysis. Underused resources were assigned to substitute for constrained resources while accounting for productivity loss.
KEY FINDINGS	4% to 29% reduction in duration
KEY LIMITATION(S)	The approach was evaluated using one previously published benchmark project and was not validated through implementation on an active construction project.

STUDY 3	
CITATION	Ballard, G. (2001). Cycle Time Reduction in Home Building. In Proceedings of the 9th Annual Conference of the International Group for Lean Construction (Vol. 6, No. 08). sn.
COUNTRY/REGION	United States
YEAR OF PUBLICATION	2001
STUDY FOCUS	Proposed an approach for reducing homebuilding cycle time through more reliable workflow and the use of multicraft teams and multiskilled workers.
STUDY CONTEXT AND DATA SOURCE	Conceptual lean-construction framework supported by illustrative homebuilding schedules, assumptions, and industry examples. No formal study sample was reported.
METHOD/APPROACH	Conceptual and descriptive analysis of even-flow production and cycle-time reduction in homebuilding.
KEY FINDINGS	Multicraft teams and multiskilled workers were proposed as ways to overlap activities, reduce activity durations and work-in-process, and improve workflow reliability. No quantified multiskilling effects were reported.
KEY LIMITATION(S)	The proposed approach was not evaluated using measured project or worker performance data and was not tested through implementation on an active construction project.

STUDY 4	
CITATION	Haas, C. T., Rodriguez, A. M., Glover, R. W., and Goodrum, P. M. (2001). Implementing A Multiskilled Workforce. Construction Management and Economics, 19(6), 633–641.
COUNTRY/REGION	United States
YEAR OF PUBLICATION	2001
STUDY FOCUS	Examined how construction companies implement multiskilling and developed a methodology for planning and managing a multiskilled workforce.
STUDY CONTEXT AND DATA SOURCE	Site visits and 84 interviews with managers and craft workers, including 69 in-person and 15 telephone interviews.
METHOD/APPROACH	Qualitative and descriptive synthesis of industry practices used to implement multiskilling.
KEY FINDINGS	The study identified implementation practices involving workforce planning, scheduling, training, compensation, and organizational support. Potential worker benefits included higher income, employability, job satisfaction, career development, and steadier employment; these benefits were discussed rather than directly measured.
KEY LIMITATION(S)	The study relied on interview and site-visit evidence from a limited number of companies and did not directly measure the effects of multiskilling on project performance or worker outcomes.

STUDY 5	
CITATION	Tam, C. M., Tong, T. K. L., Cheung, S. O., and Chan, A. P. C. (2001). Genetic Algorithm Model in Optimizing the Use of Labour. Construction Management and Economics, 19(2), 207–215.
COUNTRY/REGION	Not specified; authors based in China (Hong Kong)
YEAR OF PUBLICATION	2001
STUDY FOCUS	Developed a genetic algorithm model to optimize the allocation of flexible or multiskilled workers under different labor-availability conditions.
STUDY CONTEXT AND DATA SOURCE	Three modeled scenarios involving 5 finishing-work activities and 5 types of tradespeople, using assumed work quantities, productivity rates, and wage rates.
METHOD/APPROACH	Genetic algorithm optimization and comparison of alternative labor-allocation scenarios.
KEY FINDINGS	In a scenario involving a shortage of tilers, the optimized flexible labor arrangement increased labor cost by approximately 3.7% compared with an unlimited single-trade allocation. However, the approach enabled work to be allocated when the required specialist labor was constrained.
KEY LIMITATION(S)	Findings were based on modeled labor-allocation examples and assumed productivity and wage inputs rather than measured implementation on an active construction project.

STUDY 6	
CITATION	Gomar, J. E., Haas, C. T., and Morton, D. P. (2002). Assignment and Allocation Optimization of Partially Multiskilled Workforce. Journal of Construction Engineering and Management, 128(2), 103–109.
COUNTRY/REGION	United States
YEAR OF PUBLICATION	2002
STUDY FOCUS	Developed a model to optimize the assignment and allocation of a partially multiskilled workforce within or across construction projects.
STUDY CONTEXT AND DATA SOURCE	CII Model Plant labor-demand data and systematically varied multiskilled workforce scenarios.
METHOD/APPROACH	Linear programming optimization using GAMS, tested through 215 modeled scenarios with different proportions of multiskilled workers and assignment constraints.
KEY FINDINGS	Project benefits became marginal when multiskilled workers exceeded approximately 10%–20% of the workforce. Benefits to workers became marginal after acquiring competency in 2 or 3 crafts. Greater skill breadth increased workers' modeled employment duration.
KEY LIMITATION(S)	Findings were derived from a hypothetical model plant and simulated workforce scenarios rather than direct measurement on an active construction project.

STUDY 7	
CITATION	Koch, C., and Marton, J. (2002). Implementing Multiskilled Teams on the Construction Site: Developing A Scandinavian Model? In D. Greenwood (Ed.), Proceedings of the 18th Annual ARCOM Conference, Vol. 1, 247–256.
COUNTRY/REGION	Denmark
YEAR OF PUBLICATION	2002
STUDY FOCUS	Examined the implementation of multiskilled teams in Danish urban-renewal projects and developed a typology describing the establishment and organization of such teams.
STUDY CONTEXT AND DATA SOURCE	Three state-funded urban-renewal demonstration projects. The primary case was an ongoing ex ante study supported by participant observation, project documents, meeting reports, 8 advisory-committee meetings, and 12 interviews conducted over 10 months. Two earlier cases were examined using secondary materials.
METHOD/APPROACH	Qualitative comparative case analysis based on interpretative sociology and the development of a multiskilled-team typology.
KEY FINDINGS	Multiskilled teams were associated with improved cooperation, coordination, work satisfaction, and skill development. Implementation was limited by craft boundaries, training and wage issues, and resistance to changing established work practices.
KEY LIMITATION(S)	Findings from the primary case were preliminary because construction had not yet begun, while the other 2 cases relied on secondary materials. The study did not directly measure project-performance or worker outcomes.

STUDY 8	
CITATION	Carley, L. A., Haas, C. T., Borcherding, J. D., and Goodrum, P. M. (2003). Experiences With Multiskilling Among Non-Union Craft Workers in U.S. Industrial Construction Projects. Engineering, Construction and Architectural Management, 10(6), 374–381.
COUNTRY/REGION	United States
YEAR OF PUBLICATION	2003
STUDY FOCUS	Examined non-union craft workers' experiences with multiskilling and its relationship with wages and employment continuity.
STUDY CONTEXT AND DATA SOURCE	Interviews with 15 craft workers were used to develop a survey distributed through 10 construction companies. The analysis included responses from 721 non-union craft workers.
METHOD/APPROACH	Descriptive statistics and regression analysis of worker survey data.
KEY FINDINGS	Workers' main reasons for learning another trade were higher pay, interest in the trade, and more continuous employment. Greater skill breadth was associated with slightly higher hourly wages but had only a weak relationship with employment continuity.
KEY LIMITATION(S)	The study relied on self-reported survey data from workers in industrial construction and did not directly measure project-performance outcomes.

STUDY 9	
CITATION	Castañeda, J. A., Tucker, R. L., Haas, C. T., Glover, R. W., and Shields, D. R. (2003). A Revolutionary and Structured Approach to Construction Work Force Management: The Tier II Strategy. In Proceedings of the Construction Research Congress 2003, 1–8.
COUNTRY/REGION	United States
YEAR OF PUBLICATION	2003
STUDY FOCUS	Developed the Tier II workforce strategy, which combines craft multiskilling, basic management skills, training, and skills-based compensation.
STUDY CONTEXT AND DATA SOURCE	Baseline data from 12 industrial construction projects in 7 states and more than 500 worker surveys, including Tier II skill data from 518 workers.
METHOD/APPROACH	Descriptive analysis and development of metrics for assessing Tier II skills and implementation. Tier II scores and wage rates were compared across worker positions.
KEY FINDINGS	The Tier II strategy integrated craft multiskilling with management skills, training, and skills-based compensation. Its metric assessed workers' multiple-craft skills and the use of multiskilled workers within key crews. Preliminary results supported the feasibility of the broader Tier II strategy, but the effects of multiskilling on project performance were not separately evaluated.
KEY LIMITATION(S)	The study presented baseline and strategy-development results without evaluating project performance before and after Tier II implementation.

STUDY 10	
CITATION	Hyatt, B. A. (2003). Comparison Of Naval Construction Force Personnel and Civilian Construction Workers in the United States Utilizing the Workforce Assessment Package (Master's thesis, Monterey, California. Naval Postgraduate School).
COUNTRY/REGION	United States
YEAR OF PUBLICATION	2003
STUDY FOCUS	Examined multiskilling, training, and workforce competencies among U.S. Navy construction personnel and compared them with civilian construction workers.
STUDY CONTEXT AND DATA SOURCE	Workforce Assessment Package surveys of Naval Construction Force petty officers at training centers in California and Mississippi, compared with existing CII civilian workforce data. The Navy sample included 108 background questionnaires and 121 skill assessments.
METHOD/APPROACH	Descriptive comparison of craft certifications, training, management skills, career satisfaction, and Tier II worker scores.
KEY FINDINGS	Navy construction personnel averaged approximately two craft certifications, indicating that multiskilling was common. Builders and equipment operators had the broadest certification profiles, and nearly 90% of respondents considered multiskilled workers important. The study recommended encouraging multiskilling while maintaining worker proficiency, tracking skills, and preventing deterioration of unused skills.
KEY LIMITATION(S)	The study quantified workers' skill profiles but did not evaluate the effects of multiskilling on project performance or safety outcomes.

STUDY 11	
CITATION	Castañeda, J. A., Tucker, R. L., and Haas, C. T. (2005). Workers' Skills and Receptiveness to Operate Under the Tier II Construction Management Strategy. Journal of Construction Engineering and Management, 131(7), 799–807.
COUNTRY/REGION	United States
YEAR OF PUBLICATION	2005
STUDY FOCUS	Assessed industrial construction workers' existing Tier II skills and their receptiveness to multiskilling, additional training, and nontraditional workforce-management practices.
STUDY CONTEXT AND DATA SOURCE	Questionnaire data from more than 900 workers across 20 industrial construction projects, using worker skills, worker profile, and Tier II management questionnaires.
METHOD/APPROACH	Descriptive and exploratory analysis of Tier II skill scores, skill gaps, and worker receptiveness. Projects were selected through convenience sampling.
KEY FINDINGS	Workers possessed some Tier II technical and management skills and were generally receptive to additional training and nontraditional workforce practices, including multicrafted crews, although substantial skill gaps remained.
KEY LIMITATION(S)	The study did not measure the direct impact of multiskilling on project performance outcomes.

STUDY 12	
CITATION	Ejohwomu, O. A., Proverbs, D. G., and Olomolaiye, P. (2006). Multiskilling: A UK Construction and Building Services Perspective. In Procs 22nd Annual ARCOM Conference (pp. 4-6).
COUNTRY/REGION	United Kingdom
YEAR OF PUBLICATION	2006
STUDY FOCUS	Examined multiskilling as a response to construction skill shortages and inadequate training provision and developed a training framework for sustaining a multiskilled workforce.
STUDY CONTEXT AND DATA SOURCE	Semi-structured interviews with representatives of 43 construction and building-services companies in the Black Country region of the United Kingdom.
METHOD/APPROACH	Literature review and face-to-face survey using structured and open-ended questions. Quantitative responses were analyzed in SPSS, and narrative responses were analyzed qualitatively.
KEY FINDINGS	Multiskilling was identified as a potential response to labor shortages, low productivity, and workforce overburden in UK construction. The study also developed a Partnership in Training framework to address inadequate training provision, identified as a key barrier to developing a multiskilled workforce.
KEY LIMITATION(S)	The sample was limited to 43 organizations in one UK subregion and was not representative of the wider construction industry. The proposed training framework was conceptual and was not implemented or evaluated, and project-performance effects of multiskilling were not measured.

STUDY 13	
CITATION	McGuinness, S., and Bennett, J. (2006). Examining the Link Between Skill Shortages, Training Composition and Productivity Levels in the Construction Industry: Evidence from Northern Ireland. The International Journal of Human Resource Management, 17(2), 265–279.
COUNTRY/REGION	Northern Ireland, United Kingdom
YEAR OF PUBLICATION	2006
STUDY FOCUS	Examined multiskilled training as a response to skill shortages and changing construction practices.
STUDY CONTEXT AND DATA SOURCE	Survey of 233 construction firms representing 9,522 employees.
METHOD/APPROACH	Survey analysis and regression modeling.
KEY FINDINGS	54% of firms supported a multiskilled training strategy. Demand for multiskilled training was strongly associated with the adoption of prefabricated building techniques. Introducing a multiskilled element to training could help reduce skill shortages associated with changing construction practices. The authors cautioned that a large-scale shift from traditional single-trade training to multiskilled training could reduce worker productivity.
KEY LIMITATION(S)	Firm-level survey study; no direct observation or head-to-head comparison of multiskilled and single-skilled workers or crews.

STUDY 14	
CITATION	Srour, I. M., Haas, C. T., and Morton, D. P. (2006). Linear Programming Approach to Optimize Strategic Investment in the Construction Workforce. Journal of Construction Engineering and Management, 132(11), 1158–1166.
COUNTRY/REGION	United States
YEAR OF PUBLICATION	2006
STUDY FOCUS	Developed an optimization model for determining when to train workers in additional crafts, hire single- or multiskilled workers, and allocate labor to meet project demand at minimum cost.
STUDY CONTEXT AND DATA SOURCE	Application to the CII hypothetical petrochemical model plant using its 77-week labor-demand profile. Model inputs included assumed training and hiring costs, industry wage data, and skill-affinity data derived from a survey of 982 workers across 19 U.S. construction sites.
METHOD/APPROACH	Linear programming model (Optimal Workforce Investment Model) implemented in GAMS and solved with CPLEX. Five workforce scenarios, sensitivity analyses, and an additional comparative benefit–cost case were evaluated.
KEY FINDINGS	The model generally favored hiring multiskilled workers because their flexibility across crafts reduced the need for additional single-skilled workers. Compared with two nonoptimized hiring or cross-training approaches, the OWIM produced modeled labor-cost savings of approximately $26,000–$32,000, or about 0.3% of the approximately $9 million total labor cost
KEY LIMITATION(S)	Results were based on a hypothetical project and assumed training costs, hiring costs, skill affinities, and labor availability.

STUDY 15	
CITATION	Thomas, H. R., and Horman, M. J. (2006). Fundamental Principles of Workforce Management. Journal of Construction Engineering and Management, 132(1), 97–104.
COUNTRY/REGION	United States, Brazil, and Jordan
YEAR OF PUBLICATION	2006
STUDY FOCUS	Developed fundamental principles for effective construction workforce management, including principles for organizing and assigning multiskilled crews.
STUDY CONTEXT AND DATA SOURCE	Field productivity and workforce-management observations from 35 projects. These included 14 concrete formwork and 12 steel-reinforcement projects in the United States and Brazil, representing 104,343 work hours and 1,590 workdays, plus nine projects in the United States and Jordan.
METHOD/APPROACH	Field productivity observations, analysis of workforce-management practices, and deductive development of management principles. The proposed principles were reviewed with construction practitioners.
KEY FINDINGS	Effective multiskilling requires flexible team sizes and assignments based on available work, expected production, and the time needed for each task. Field examples indicated that multiskilling supported good productivity when workers were allocated effectively, but poor task and team allocation reduced performance.
KEY LIMITATION(S)	The study did not isolate or statistically quantify the effect of multiskilling on productivity. Its principles were based largely on field observations, selected examples, and deductive reasoning rather than controlled comparisons.

STUDY 16	
CITATION	de Miranda Filho, A. N., Moreira da Costa, J., and Heineck, L. F. M. (2007). Assessing the Effects of Structural Differences on Action, Reaction and Conformation in Construction Projects. Proc., 15th Annual Conf. of the International Group for Lean Construction, 380–389.
COUNTRY/REGION	Brazil
YEAR OF PUBLICATION	2007
STUDY FOCUS	Examined multiskilled teams as a form of labor flexibility within different construction organizational structures.
STUDY CONTEXT AND DATA SOURCE	Five high-rise building firms in Fortaleza, Brazil; 8 construction sites and interviews with 15 project managers and CEOs.
METHOD/APPROACH	Exploratory comparative case study using site visits, semi-structured interviews, and manager ratings.
KEY FINDINGS	Firms using multiskilled teams moved workers between functions to absorb demand fluctuations. Managers reported fewer handovers and reduced managerial intervention in firms using multiskilled teams. Firms using multiskilled teams relied less on capacity and work-in-process buffers. Multiskilling was implemented together with complementary organizational and management practices.
KEY LIMITATION(S)	Findings were primarily interview-based and did not isolate or quantify the performance effect of multiskilling.

STUDY 17	
CITATION	Sacks, R., and Goldin, M. (2007). Lean Management Model for Construction of High-Rise Apartment Buildings. Journal of Construction Engineering and Management, 133(5), 374–384.
COUNTRY/REGION	Not specified; authors based in Israel
YEAR OF PUBLICATION	2007
STUDY FOCUS	Developed a lean management approach for high-rise apartment finishing that included multiskilling, pull flow, reduced batch sizes, and work restructuring.
STUDY CONTEXT AND DATA SOURCE	Project records from 3 high-rise projects (276 apartments), supplemented by management simulations and a 48-unit pilot project.
METHOD/APPROACH	Project-data and process analysis, management simulation game, discrete-event simulation, and pilot implementation.
KEY FINDINGS	Multiskilling was proposed to reduce work-team interfaces and allow larger packages of continuous work. Multiskilling increased opportunities for teams to work in parallel and reduce queuing. In the combined lean model that included multiskilling, throughput increased by about 54% and cycle time decreased by about 58% compared with the conventional approach.
KEY LIMITATION(S)	Reported performance improvements came from a combined lean model rather than multiskilling alone; multiskilling was not implemented in the pilot project, so no field-based multiskilling effect was measured.

STUDY 18	
CITATION	Ejohwomu, O. A., Proverbs, D. G., and Olomolaiye, P. (2008). The Impact of Multiskilling on UK's Construction Manpower. Proceedings of the Institution of Civil Engineers—Management, Procurement and Law, 161(1), 25–30.
COUNTRY/REGION	United Kingdom
YEAR OF PUBLICATION	2008
STUDY FOCUS	Evaluated the potential impact of different trade-skill combinations on construction output and developed an optimization model for multiskilling in traditional trades.
STUDY CONTEXT AND DATA SOURCE	A 43-year time series of UK construction output and 23 manpower categories obtained primarily from annual construction statistics.
METHOD/APPROACH	Pearson correlation, factor analysis, and multiple linear regression were used to evaluate two-, three-, and four-skill combinations. Eleven exploratory models were developed, and the selected model was validated using adjusted R^2.
KEY FINDINGS	The modeled benefits of multiskilling showed diminishing returns, with weak correlations between construction output and workers possessing three or more skill combinations Dual-skill combinations were identified as the most efficient arrangement when compatible skills were paired. Based on one of the regression models, the study indicated that inappropriate skill combinations could result in negative productivity.
KEY LIMITATION(S)	The study used aggregate historical manpower data rather than observations of individual multiskilled workers.

STUDY 19	
CITATION	Lobo, Y. B., and Wilkinson, S. (2008). New Approaches to Solving the Skills Shortages in the New Zealand Construction Industry. Engineering, Construction and Architectural Management, 15(1), 42–53.
COUNTRY/REGION	New Zealand
YEAR OF PUBLICATION	2008
STUDY FOCUS	Assessed existing and proposed approaches for addressing construction skill shortages in New Zealand and identified potential long-term strategies.
STUDY CONTEXT AND DATA SOURCE	Semi-structured interviews with 35 construction-industry representatives from government, contractors, consultants, professional and industry associations, academia, unions, technical organizations, and property development.
METHOD/APPROACH	Mixed qualitative and quantitative approach using semi-structured interviews, grounded-theory analysis, descriptive statistics, and NVivo.
KEY FINDINGS	Multiskilling was discussed, based on previous studies, as a potential strategy for broadening workers' skills and responding to skill shortages, but it was not a prominent strategy identified in the New Zealand interview findings
KEY LIMITATION(S)	The study did not collect data on actual multiskilling practices or evaluate their workforce or project-performance effects.

STUDY 20	
CITATION	Lill, I. (2009). Multiskilling in Construction—A Strategy for Stable Employment. Technological and Economic Development of Economy, 15(4), 540–560.
COUNTRY/REGION	Estonia
YEAR OF PUBLICATION	2009
STUDY FOCUS	Evaluated multiskilling as a labor-management strategy for improving workload stability and economic outcomes for contractors, owners, and workers.
STUDY CONTEXT AND DATA SOURCE	Simulation of an average construction firm operating multiple projects, represented through network schedules and activity-level labor, duration, cost, material, machinery, and financial parameters.
METHOD/APPROACH	Simulation modeling using an existing construction-firm management system reconfigured to evaluate multiskilling. The number and combinations of trades assigned to workers were varied while total labor remained constant, and effects on construction duration, contractor costs, and owner revenue were compared.
KEY FINDINGS	Using multiskilled workers reduced modeled construction duration by approximately 20% through more stable and complete workforce utilization. Combining four trades reduced modeled construction cost by approximately 3% and increased the owner's potential revenue by approximately 7%. Benefits became relatively insignificant when workers were assigned more than four trades.
KEY LIMITATION(S)	The study is based on simulations rather than onsite construction project data.

STUDY 21	
CITATION	Wang, Y., Goodrum, P. M., Haas, C. T., and Glover, R. W. (2009). Analysis Of Observed Skill Affinity Patterns and Motivation for Multiskilling Among Craft Workers in the U.S. Industrial Construction Sector. Journal of Construction Engineering and Management, 135(10), 999–1008.
COUNTRY/REGION	United States
YEAR OF PUBLICATION	2009
STUDY FOCUS	Examined observed trade-skill combinations, worker characteristics associated with multiskilling, and workers' motivation for acquiring multiple skills.
STUDY CONTEXT AND DATA SOURCE	Two datasets were analyzed: NCACP assessment records for 66,410 workers tested between 2000 and 2006, including 1,579 who sought certification in multiple skills, and survey data from 849 craft workers across 19 U.S. industrial construction projects.
METHOD/APPROACH	Pearson correlation and hierarchical cluster analyses were used to identify skill pairings and broader skill groups. Tests of proportion and a t-test examined differences by race/ethnicity and work experience.
KEY FINDINGS	Observed skills clustered into broad civil, mechanical, electrical, and general-support groups. Workers primarily combined related skills that required similar knowledge or were performed concurrently during the same construction phase. Increased work functionality appeared to be a stronger motivation for multiskilling than extending project employment duration. Workers seeking multiple certifications had significantly more construction experience than the broader NCACP testing population.
KEY LIMITATION(S)	The study focused on skill-clustering patterns and did not assess the direct effects of multiskilling on project-performance outcomes.

STUDY 22	
CITATION	Hyari, K., El-Mashaleh, M., and Kandil, A. (2010). Optimal Assignment of Multiskilled Labor in Building Construction Projects. International Journal of Construction Education and Research, 6(1), 70–80.
COUNTRY/REGION	Not specified; authors based in Jordan and the United States
YEAR OF PUBLICATION	2010
STUDY FOCUS	Developed a model for assigning multiskilled workers to daily construction tasks while minimizing labor cost.
STUDY CONTEXT AND DATA SOURCE	Finishing-work assignment example from a prior study involving 5 tasks, 5 worker types, and 3 scenarios.
METHOD/APPROACH	Mixed-integer linear programming implemented using Excel Solver.
KEY FINDINGS	The model used workers' secondary skills to fill otherwise unused work time and support assignments across tasks. Across the three scenarios, the model required about 2%–4% fewer workers than the previous assignment model used in the prior study. Labor cost was approximately 2%–4% lower than the model in a prior study. The model accommodated limited labor availability and changes in workload while considering worker skills, productivity, and availability.
KEY LIMITATION(S)	Based on a modeled application example from a prior study rather than an active construction project; compared alternative multiskilled assignment models rather than multiskilled and single-skilled workforces.

STUDY 23	
CITATION	Wongwai, N., and Malaikrisanachalee, S. (2011). Augmented Heuristic Algorithm for Multi-Skilled Resource Scheduling. Automation in Construction, 20(4), 429–445.
COUNTRY/REGION	Not specified; authors based in Thailand
YEAR OF PUBLICATION	2011
STUDY FOCUS	Developed an augmented heuristic algorithm for scheduling multiskilled resources to improve resource substitution and reduce project duration.
STUDY CONTEXT AND DATA SOURCE	Model-based case studies using project activity networks, resource requirements and limits, worker-substitution rules, and team-constraint assumptions. The main case contained 17 activities and 5 resource types, followed by 10 additional test cases.
METHOD/APPROACH	Development and testing of the Augmented Heuristic Algorithm for Multi-Skilled Resource Scheduling (AHAMRS). Results were compared with single-skilled scheduling, an existing multiskilled heuristic, and schedules with and without team constraints.
KEY FINDINGS	Existing multiskilling scheduling reduced duration by about 18%–23% compared with single-skilling; AHAMRS reduced duration by about 32%–39% compared with the single-skilling baseline
KEY LIMITATION(S)	The study used assumed case studies with hypothetical project and resource information rather than data from active construction projects.

STUDY 24	
CITATION	Liu, S.-S., and Wang, C.-J. (2012). Optimizing Linear Project Scheduling with Multi-Skilled Crews. Automation in Construction, 24, 16–23.
COUNTRY/REGION	Not specified; authors based in Taiwan
YEAR OF PUBLICATION	2012
STUDY FOCUS	Developed an optimization model for integrating single-skilled and temporarily hired multiskilled crews to minimize the duration of linear construction projects and improve crew continuity.
STUDY CONTEXT AND DATA SOURCE	A model-based bridge example consisting of four sections and five repetitive activities: excavation, foundations, columns, beams, and slabs. Assumed work quantities, crew production rates, and costs were obtained from a previously published example.
METHOD/APPROACH	Constraint-programming optimization with heuristic crew-selection and scheduling rules. Two scenarios were evaluated: minimizing project duration while allowing interruptions and minimizing duration while requiring uninterrupted work continuity.
KEY FINDINGS	The model demonstrated how single-skilled and temporarily hired multiskilled crews could be jointly selected and scheduled to minimize project duration while accounting for crew continuity and outsourcing costs.
KEY LIMITATION(S)	The model was demonstrated using an assumed bridge example and did not compare the multiskilled solution with an equivalent single-skilled baseline; therefore, the project-performance effect attributable specifically to multiskilling could not be determined.

STUDY 25	
CITATION	Florez, L., Castro-Lacouture, D., and Medaglia, A. L. (2013). Sustainable Workforce Scheduling in Construction Program Management. Journal of the Operational Research Society, 64(8), 1169–1181.
COUNTRY/REGION	Not specified; authors based in Colombia and the United States
YEAR OF PUBLICATION	2013
STUDY FOCUS	Examined how multiskilling can support labor stability while balancing construction program time and cost.
STUDY CONTEXT AND DATA SOURCE	Modeled construction program of 10 projects using assumed project characteristics, worker skills, resource requirements, and cost inputs.
METHOD/APPROACH	Multiobjective mixed-integer programming with lexicographic and ε-constraint optimization.
KEY FINDINGS	Using multiskilled workers reduced modeled program completion time from 33 to 31 periods, about 6%. Modeled total cost was about 2% lower with multiskilled workers. Multiskilling reduced labor fluctuations and the number of worker terminations. The model showed that workers could shift between skills to support a more stable workforce across projects.
KEY LIMITATION(S)	Results were generated from a modeled 10-project construction program rather than observed implementation on active projects.

STUDY 26	
CITATION	Arashpour, M., Wakefield, R., Blismas, N., and Minas, J. (2015). Optimization of Process Integration and Multi-Skilled Resource Utilization in Off-Site Construction. Automation in Construction, 50, 72–80.
COUNTRY/REGION	Australia
YEAR OF PUBLICATION	2015
STUDY FOCUS	Evaluated alternative cross-training strategies for creating and optimally utilizing multiskilled workers in off-site construction production systems.
STUDY CONTEXT AND DATA SOURCE	Production data from two prefabricated-house manufacturing facilities in Melbourne and Brisbane, Australia. The facilities produced components such as wall panels, steel frames, and roof trusses.
METHOD/APPROACH	Formulated the optimal number of additional skills as a constrained transportation problem and conducted 1,080 discrete-event simulation experiments. Five multiskilling strategies were compared with a single-skilled, no-flexibility baseline under varying levels of capacity imbalance, processing-time variability, and work-in-process.
KEY FINDINGS	Multiskilling improved throughput, cycle time, and resource utilization compared with the single-skilled baseline. Throughput rate improvements ranged from 9% to 25% under one production setting and up to 2% to 77% under a higher-variability/high-imbalance setting. Completion-time reductions ranged from about 9% to 20% in the main production setting and from about 2% to 44% in the higher-variability/high-imbalance setting.
KEY LIMITATION(S)	The reported performance effects were generated through simulation models calibrated and validated using data from two off-site production facilities, rather than through actual implementation of the multiskilling strategies.

STUDY 27	
CITATION	Pandey, P., and Maheswari, J. U. (2015). Improvised Scheduling Framework Integrating Work Study, Multiskilling, and Dynamic Scheduling for Repetitive Construction Projects. In Proc., 32th ISARC Conf (pp. 1-8).
COUNTRY/REGION	Not specified; authors based in India
YEAR OF PUBLICATION	2015
STUDY FOCUS	Proposed a scheduling framework integrating work study, multiskilling, and dynamic scheduling to improve workforce utilization and project performance in repetitive construction.
STUDY CONTEXT AND DATA SOURCE	A mass-housing project consisting of 50 residential blocks, with four dwelling units per block. Activity quantities, crew requirements, and schedule information were obtained from project drawings, records, and expert input.
METHOD/APPROACH	Line-of-balance scheduling, work-study analysis, and scenario-based restructuring of selected single-skilled trades into multiskilled crews and workers.
KEY FINDINGS	For MS Type 1, the combined average manpower requirement decreased from 45.6 workers for the separate shuttering and carpentry crews to 22 workers for the multiskilled crew, representing an approximately 52% reduction. Employment duration increased by 67% compared with the shuttering crew and by 179% compared with the carpenter crew. For MS Type 2, the average requirement for single-skilled bar benders decreased from 76.3 to 55.2 workers, representing a 27.7% reduction, while the average requirement for single-skilled masons decreased from 41.8 to 19.8 workers, representing a 53% reduction. The multiskilled bar-bender–mason workers' employment duration was 6% longer than that of masons and 51% longer than that of bar benders.
KEY LIMITATION(S)	The multiskilling results were derived from schedule-based scenarios and assumed trade combinations rather than observed implementation. Project-duration improvements were produced by work study and dynamic scheduling rather than being attributable specifically to multiskilling.

STUDY 28	
CITATION	Ahmadian Fard Fini, A., Rashidi, T. H., Akbarnezhad, A., and Waller, S. T. (2016). Incorporating Multiskilling and Learning in the Optimization of Crew Composition. Journal of Construction Engineering and Management, 142(5), 04015106.
COUNTRY/REGION	Australia
YEAR OF PUBLICATION	2016
STUDY FOCUS	Developed a model for optimizing the composition of single-skilled and multiskilled crews while accounting for worker experience and learning to minimize project duration.
STUDY CONTEXT AND DATA SOURCE	A three-story residential building with an underground car park in Melbourne, Australia. Project quantities, workforce availability, and cost data were supplemented with five years of contractor performance records from three similar projects.
METHOD/APPROACH	Mathematical optimization using a hybrid method combining constraint programming, statistical analysis, and a genetic algorithm.
KEY FINDINGS	The optimized crew composition reduced modeled project duration from the contractor's 61-day estimate to 44.5 days, a 27% reduction. The optimized model reduced duration by 22% compared with scheduling the same multiskilled crew without accounting for learning effects.
KEY LIMITATION(S)	The findings are based on one modeled case and were not verified through field implementation.

STUDY 29	
CITATION	Ho, P. H. K. (2016). Labour and Skill Shortages in Hong Kong's Construction Industry. Engineering, Construction and Architectural Management, 23(4), 533–550.
COUNTRY/REGION	China (Hong Kong)
YEAR OF PUBLICATION	2016
STUDY FOCUS	Identified and assessed strategies for addressing labor and skill shortages in Hong Kong's construction industry and developed a conceptual labor-supply model.
STUDY CONTEXT AND DATA SOURCE	Two discussion forums involving 30 industry experts and a questionnaire survey completed by 438 construction professionals and senior managers.
METHOD/APPROACH	Mixed-method approach using expert discussion forums, a seven-point Likert-scale survey, descriptive analysis, and grounded theory.
KEY FINDINGS	Developing multiskilled workers was rated 4.76 out of 7 and was considered a medium- to long-term strategy for reducing labor demand. It was viewed as particularly suitable for fitting-out, maintenance, alteration, and small-scale projects involving varied tasks.
KEY LIMITATION(S)	Multiskilling was assessed through expert and industry perceptions rather than actual implementation.

STUDY 30	
CITATION	Ahmadian Fard Fini, A., Akbarnezhad, A., Rashidi, T. H., and Waller, S. T. (2017). Job Assignment Based on Brain Demands and Human Resource Strategies. Journal of Construction Engineering and Management, 143(5), 04016123.
COUNTRY/REGION	Australia
YEAR OF PUBLICATION	2017
STUDY FOCUS	Developed a crew-level framework for assigning construction tasks based on workers' capabilities, workload demands, and human-resource strategies, including multiskilling.
STUDY CONTEXT AND DATA SOURCE	A concreting operation involving reinforcement, formwork, and concrete placement in a three-story residential building with underground parking in Melbourne. The model used productivity data collected over 12 days from 651 observations and historical performance data from three similar projects.
METHOD/APPROACH	Mathematical workload modeling and discrete-event simulation were used to compare single-skilled and multiskilled task-assignment scenarios based on visual, auditory, cognitive, and psychomotor demands.
KEY FINDINGS	Multiskilling increased modeled daily throughput from 6.53 to 8.38 m^3/day, representing a 28% improvement over the single-skilled scenario. The model showed that allowing workers to share tasks across trade boundaries could improve both workload distribution and production performance.
KEY LIMITATION(S)	The multiskilling results were simulated for one concreting project and were not verified through onsite implementation.

STUDY 31	
CITATION	Gouda, A., Hosny, O., and Nassar, K. (2017). Optimal Crew Routing for Linear Repetitive Projects Using Graph Theory. Automation in Construction, 81, 411–421.
COUNTRY/REGION	Not specified; authors based in Egypt
YEAR OF PUBLICATION	2017
STUDY FOCUS	Developed an approach for routing multitasking skilled crews across activities in linear repetitive construction projects.
STUDY CONTEXT AND DATA SOURCE	Real sewage-pipeline installation case used to model 10 repetitive 4-km pipeline units, totaling 40 km.
METHOD/APPROACH	CPM/LOB scheduling integrated with graph-theory optimization and MATLAB-based crew routing.
KEY FINDINGS	Multitasking crews were routed across different activities and project units while maintaining work continuity. The model reduced the required crews from 14 to 9, about 36%, after introducing multitasking crew assignments. The approach increased the duration of crew utilization by routing the same crews through multiple activities. The model demonstrated how flexible crew routing could help address resource constraints in repetitive projects.
KEY LIMITATION(S)	Results were generated through a modeled crew-routing application rather than observed implementation; learning effects from moving crews between different activities were not considered.

STUDY 32	
CITATION	Arashpour, M., Wakefield, R., Abbasi, B., Arashpour, M., and Hosseini, R. (2018a). Optimal Process Integration Architectures in Off-Site Construction: Theorizing the Use of Multi-Skilled Resources. Architectural Engineering and Design Management, 14(1-2), 46-59.
COUNTRY/REGION	Australia
YEAR OF PUBLICATION	2018
STUDY FOCUS	Evaluated alternative process-integration arrangements for deploying multiskilled workers in off-site construction.
STUDY CONTEXT AND DATA SOURCE	Production data from three off-site manufacturers in Sydney, Brisbane, and Melbourne that produced modular kitchen, bathroom, and laundry pods. Cross-training cost and time data were obtained from company records, while 47 managers, supervisors, and superintendents assessed network logic, skill transferability, and safety.
METHOD/APPROACH	Fuzzy–TOPSIS multi-criteria decision analysis comparing full integration, skill chaining, upstream integration, downstream integration, and direct integration.
KEY FINDINGS	Skill chaining was the preferred multiskilling arrangement, followed by direct integration, because both redirected workers' unused capacity to bottleneck activities with less cross-training than full integration. Full integration ranked lowest because it required substantially more time and cost to train workers across the entire production network.
KEY LIMITATION(S)	The analysis covered three off-site manufacturers and ranked multiskilling arrangements rather than measuring their effects on project performance.

STUDY 33	
CITATION	Arashpour, M., Kamat, V., Bai, Y., Wakefield, R., and Abbasi, B. (2018b). Optimization Modeling of Multi-Skilled Resources in Prefabrication: Theorizing Cost Analysis of Process Integration in Off-Site Construction. Automation in Construction, 95, 1–9.
COUNTRY/REGION	Australia
YEAR OF PUBLICATION	2018
STUDY FOCUS	Developed a resource-planning model that accounts for the cost and time required to cross-train and deploy multiskilled workers in off-site construction.
STUDY CONTEXT AND DATA SOURCE	Seven months of worker-hour demand and workforce-turnover data from two prefabrication facilities in Melbourne and Brisbane.
METHOD/APPROACH	Integer, linear, and probabilistic optimization models, supported by sensitivity analysis, were used to determine the required numbers of multiskilled workers and trainees under varying demand and turnover conditions.
KEY FINDINGS	Planning for multiskilled workers needed to begin before the production period to account for cross-training time. Cross-training duration was the strongest influence on modeled production time.
KEY LIMITATION(S)	The study did not assess the direct impact of multiskilling on project performance outcomes.

STUDY 34	
CITATION	Akinola, J. A. (2019). Challenges Of Adopting Multiskilling Strategy to Quantity Surveying Practice in Nigeria. IOSR Journal of Mechanical and Civil Engineering, 16(6), 58–66.
COUNTRY/REGION	Nigeria
YEAR OF PUBLICATION	2019
STUDY FOCUS	Examined the factors motivating quantity surveyors to acquire additional professional skills and the challenges affecting adoption of multiskilling by quantity surveying firms.
STUDY CONTEXT AND DATA SOURCE	Questionnaire responses from 66 multiskilled quantity surveyors and diversified quantity surveying firms identified through a pilot survey and snowball sampling.
METHOD/APPROACH	Questionnaire survey analyzed using mean item scores and chi-square cross-tabulation.
KEY FINDINGS	The strongest motivations for multiskilling were competency, competitive advantage, and the ability to customize services, with mean scores of 4.33, 4.32, and 4.06, respectively. The leading adoption challenges were the cost of engaging multiskilled personnel, task-specific job requirements, and pride in professional specialization, with mean scores of 3.88, 3.48, and 3.39, respectively.
KEY LIMITATION(S)	The findings were based on perceptions from quantity surveyors identified through snowball sampling and may not apply beyond quantity surveying practice.

STUDY 35	
CITATION	Korb, S., Telyas, A., Sacks, R., and Duka, A. (2019). Evaluating Multiskilling in Residential Construction Projects Using Regional Industry Simulation. In Proceedings of the 27th Annual Conference of the International Group for Lean Construction (pp. 1229–1240).
COUNTRY/REGION	United States
YEAR OF PUBLICATION	2019
STUDY FOCUS	Evaluated the use of multiskilled work cells and smaller production batches in residential construction within a regional construction market.
STUDY CONTEXT AND DATA SOURCE	The planned 66-unit Makerhoods residential development in Newark, New Jersey. Model inputs included project quantities, RSMeans production rates, regional construction activity, and local trade-labor data.
METHOD/APPROACH	Agent-based regional industry simulation using LeapconX in NetLogo. Traditional trade-specific subcontracting was compared with a scenario using multiskilled crews and reduced batch sizes.
KEY FINDINGS	Combining multiskilled crews with reduced batch sizes decreased the modeled duration of the Makerhoods project by approximately 39% and reduced the duration of the overall regional simulation by approximately 8%. The multiskilled scenario also improved subcontractor utilization by reducing waiting time caused by differences in trade work durations.
KEY LIMITATION(S)	Multiskilling and reduced batch size were tested together, so their individual effects could not be separated. The results were also based on simulation rather than field implementation.

STUDY 36	
CITATION	Nasirian, A., Arashpour, M., and Abbasi, B. (2019a). Critical Literature Review of Labor Multiskilling in Construction. Journal of Construction Engineering and Management, 145(1), 04018113.
COUNTRY/REGION	International; not location-specific
YEAR OF PUBLICATION	2019
STUDY FOCUS	Reviewed and classified construction multiskilling research to identify common strategies, application contexts, collateral effects, and research gaps.
STUDY CONTEXT AND DATA SOURCE	A review of 61 publications on construction multiskilling published from 1998 onward, including journal articles, conference papers, and selected industry and government reports.
METHOD/APPROACH	Two-stage literature search and screening using construction-management journals, Google Scholar, Web of Science, Scopus, and reference tracking. The studies were classified through a conceptual framework and keyword-network analysis.
KEY FINDINGS	Multiskilling research covered three main contexts: onsite construction, off-site construction, and repetitive construction. Strategies ranged from partial cross-training, such as dual-skilling, chaining, and direct capacity balancing, to full cross-training and multiskilled teams. The suitability of a multiskilling strategy depended on the project context, intended benefits, and possible effects such as training costs, reduced efficiency, skill loss, higher wages, and worker-related concerns. Prior research concentrated mainly on scheduling, optimization, and simulation, while human-resource and learning issues received less attention.
KEY LIMITATION(S)	The review was limited to publications available through the selected sources and did not independently test the identified strategies.

STUDY 37	
CITATION	Nasirian, A., Arashpour, M., Abbasi, B., and Akbarnezhad, A. (2019b). Optimal Work Assignment to Multiskilled Resources in Prefabricated Construction. Journal of Construction Engineering and Management, 145(4), 04019011.
COUNTRY/REGION	Australia
YEAR OF PUBLICATION	2019
STUDY FOCUS	Evaluated alternative single-skilled and multiskilled workforce strategies under different levels of production variability and bottleneck conditions in off-site construction.
STUDY CONTEXT AND DATA SOURCE	A modular prefabrication factory in Melbourne producing bathroom pods through 12 sequential workstations. Model inputs were obtained through onsite observation, production and financial records, and interviews with the factory manager.
METHOD/APPROACH	A flow-shop-based mathematical optimization model was used to compare no cross-training, additional single-skilled workers, direct capacity balancing, skill chaining, and hiring multiskilled workers under no-, medium-, and high-variability conditions.
KEY FINDINGS	Compared with the no-cross-training baseline, modeled makespan decreased by 22%–27% with additional single-skilled workers, 28%–32% with direct capacity balancing, 26%–31% with skill chaining, and 31%–41% with hired multiskilled workers, depending on the variability strategy. Labor-cost results varied by production condition. Direct capacity balancing reduced cost by 25%–42%, while hired multiskilled workers increased cost by 17%–26%. Additional single-skilled workers increased cost by 78% under no variability but reduced it by 32%–38% under medium and high variability. Similarly, skill chaining increased cost by 26% under no variability but reduced it by 49%–58% under medium and high variability.
KEY LIMITATION(S)	The model was tested on one factory, and the assumed effects of multiskilling were not verified through implementation.

STUDY 38	
CITATION	Nasirian, A., Arashpour, M., Abbasi, B., Zavadskas, E. K., and Akbarnezhad, A. (2019c). Skill Set Configuration in Prefabricated Construction: Hybrid Optimization and Multicriteria Decision-Making Approach. Journal of Construction Engineering and Management, 145(9), 04019050.
COUNTRY/REGION	Australia
YEAR OF PUBLICATION	2019
STUDY FOCUS	Evaluated and ranked alternative multiskilling configurations for addressing production bottlenecks in off-site construction while considering operational, financial, and workforce-related criteria.
STUDY CONTEXT AND DATA SOURCE	A modular prefabrication factory in Melbourne producing bathroom pods through 12 workstations. Data were obtained through factory observations, production and financial records, five production orders, an interview with the site manager, and input from four experts.
METHOD/APPROACH	Hybrid approach combining flow-shop optimization, Delphi, Analytic Hierarchy Process, PROMETHEE multicriteria analysis, and sensitivity analysis. Eleven configurations were compared, including no cross-training, chaining, direct capacity balancing, upstream and downstream cross-training, and hiring dual-skilled or four-skills-helper workers.
KEY FINDINGS	Modeled makespan decreased by 17%–53% across the multiskilling strategies compared with the no-cross-training baseline. Salary costs increased by 4%–37% across the multiskilling strategies compared with the no-cross-training baseline.
KEY LIMITATION(S)	The findings were based on one factory and modeled strategies rather than actual implementation.

STUDY 39	
CITATION	Avva, V. S. R., and Chamberlin, S. K. (2020). Multi-Skilling And Crosstraining of Labor in Prefabrication Construction Industry by MCDM Method. Materials Today: Proceedings, 33, 620–625.
COUNTRY/REGION	Not specified; authors based in India
YEAR OF PUBLICATION	2020
STUDY FOCUS	Ranked alternative multiskilling and cross-training strategies for addressing workload imbalance in prefabricated construction.
STUDY CONTEXT AND DATA SOURCE	A prefabrication production system containing 12 workstations, including framing, caulking, plumbing, carpentry, electrical work, and finishing activities. The paper does not clearly describe an independent factory location or original data-collection process.
METHOD/APPROACH	Multicriteria decision analysis combining the Analytic Hierarchy Process and ELECTRE to compare no cross-training, training existing workers, and hiring workers with different combinations of skills.
KEY FINDINGS	Hiring workers with four skill areas and cross-training existing workers for adjacent activities were the highest-ranked multiskilling options. No cross-training and upstream or downstream cross-training were among the lowest-ranked alternatives.
KEY LIMITATION(S)	The study did not clearly identify an independent dataset and ranked multiskilling strategies without directly quantifying their effects on project performance.

STUDY 40	
CITATION	Li, Q., Sun, Q., Tao, S., and Gao, X. (2020). Multi-Skill Project Scheduling with Skill Evolution and Cooperation Effectiveness. Engineering, Construction and Architectural Management, 27(8), 2023–2045.
COUNTRY/REGION	China
YEAR OF PUBLICATION	2020
STUDY FOCUS	Developed a project-scheduling model for assigning multiskilled personnel while accounting for learning-based skill development and cooperation among team members.
STUDY CONTEXT AND DATA SOURCE	A simplified BIM consulting project for an 18-story hospital building in Nanjing, China. The case included nine activities, eight employees, three skill types, and a ten-month project deadline.
METHOD/APPROACH	Bi-objective nonlinear integer programming, linearization, and the ε-constraint method were used to balance project effectiveness and skill development. Three skill-development measures were evaluated, and the models were solved using CPLEX.
KEY FINDINGS	The model showed a trade-off between project effectiveness and the development of workers' multiple skills. However, the study did not isolate or quantify the effect of multiskilling compared with a single-skilled workforce.
KEY LIMITATION(S)	The study assumed a multiskilled workforce and did not compare it with a single-skilled alternative.

STUDY 41	
CITATION	Sarihi, M., Shahhosseini, V., and Banki, M. T. (2020). Multiskilled Project Management Workforce Assignment Across Multiple Projects Regarding Competency. Journal of Construction Engineering and Management, 146(12), 04020134.
COUNTRY/REGION	Not specified; authors based in Iran
YEAR OF PUBLICATION	2020
STUDY FOCUS	Developed a model for assigning multiskilled project-management personnel across multiple projects while considering worker competency, cost, resource utilization, and employment stability.
STUDY CONTEXT AND DATA SOURCE	A total of 480 standard resource-constrained project-scheduling cases grouped into 96 hypothetical companies, each with five simultaneous projects. Worker competency and cost data were obtained from an assumed human-resources database.
METHOD/APPROACH	Network-flow modeling and constraint-programming optimization implemented in GAMS and CPLEX. The proposed model was compared with complete resource leveling, maximum-period demand, and internal-workers-only assignment methods.
KEY FINDINGS	The proposed model reduced the number of allocated workers in 93 of the 96 project groups compared with complete resource leveling, with reductions reaching 40% in some cases. Average paid cost was 9% lower than when only internal workers were used, although it remained approximately 6% above the initial planned cost. These results reflect the complete assignment model and cannot be attributed specifically to multiskilling.
KEY LIMITATION(S)	The study used standard scheduling cases and assumed workforce data and did not isolate the effect of multiskilling from the other model features.

STUDY 42	
CITATION	Shang, G., Low, S. P., and Wee, J. H. (2020). Drivers And Barriers for Multiskilling Workers in the Singapore Construction Industry. International Journal of Construction Management, 20(4), 289–304.
COUNTRY/REGION	Singapore
YEAR OF PUBLICATION	2020
STUDY FOCUS	Assessed the adoption, perceived benefits, drivers, and barriers associated with Singapore's construction Multiskilling Scheme using an institutional-theory framework.
STUDY CONTEXT AND DATA SOURCE	Survey responses from 42 construction employers, including 36 whose firms were registered under the Multiskilling Scheme, followed by interviews with representatives of three construction firms and one government officer.
METHOD/APPROACH	Mixed-method research comprising a Likert-scale questionnaire, descriptive analysis and t-tests, followed by interviews used to interpret and validate the survey findings.
KEY FINDINGS	Adoption of the Multiskilling Scheme was driven mainly by lower foreign-worker levies, regulatory compliance, and worker-upgrading requirements rather than operational benefits. Employers perceived that multiskilling improved worker competence, deployment flexibility, and retention, while labor-cost and safety benefits were less evident. Barriers were generally limited, although the nature of construction work, training responsibility, and worker mobility affected implementation; some firms also selected easily attainable rather than complementary second skills.
KEY LIMITATION(S)	The study relied on perceptions from a relatively small employer sample and did not directly measure the effects of multiskilling on project performance.

STUDY 43	
CITATION	Albattah, M. A., Goodrum, P. M., Littlejohn, R., and Taylor, T. R. B. (2022). A Comparative Analysis of the Utilization of Multiskilling Among US Hispanic and Non-Hispanic Construction Craft Workers. International Journal of Construction Management, 22(3), 331–341.
COUNTRY/REGION	United States
YEAR OF PUBLICATION	2022
STUDY FOCUS	Compared multiskilling participation, formal training, and skill-combination patterns among Hispanic and non-Hispanic construction craft workers.
STUDY CONTEXT AND DATA SOURCE	NCCER National Craft Assessment and Certification Program records from 2005–2014. The analysis included 20,789 workers who attempted assessments in two or more different certificates: 6,159 Hispanic and 14,630 non-Hispanic workers.
METHOD/APPROACH	Chi-square testing compared training and multiskilling rates. Skill matrices identified dual-skill combinations, while categorical principal component analysis identified combinations involving more than two skills.
KEY FINDINGS	Hispanic workers had lower multiskilling attainment than non-Hispanic workers, but formal training rates among multiskilled workers were similar. Dual-skill combinations were largely similar between the two groups, while combinations involving more than two skills differed.
KEY LIMITATION(S)	The study focused on training access and multiskilling attainment patterns and did not assess whether different skill combinations affected project performance.

STUDY 44	
CITATION	Araya, F. (2022). Modeling The Influence of Multiskilled Construction Workers in the Context of the COVID-19 Pandemic Using an Agent-Based Approach. Revista de la Construcción, 21(1), 105–117.
COUNTRY/REGION	Not specified; author based in Chile
YEAR OF PUBLICATION	2022
STUDY FOCUS	Evaluated whether multiskilled workers could reduce workforce shortages on critical construction activities during COVID-19 disruptions.
STUDY CONTEXT AND DATA SOURCE	A hypothetical three-month construction project with 100 workers. Six scenarios varied the workforce required for critical activities from 10% to 60%, while the proportion of multiskilled workers was set at 0%, 10%, or 20%.
METHOD/APPROACH	Agent-based simulation developed in AnyLogic, with stochastic infection rates and sensitivity analysis. The model was reviewed by two construction subject-matter experts.
KEY FINDINGS	Increasing the proportion of multiskilled workers consistently reduced the modeled deficit of workers required for critical activities. In the most demanding scenario, increasing multiskilled workers from 0% to 20% reduced the average workforce deficit from 33.4% to 16.8%, approximately a 50% reduction. A 20% multiskilled workforce eliminated the modeled deficit when critical activities required 10%–30% of the workforce.
KEY LIMITATION(S)	The study relied on simulations that may not fully capture real-world workforce dynamics, differences in workers' skill combinations, or operational constraints, and the findings were not validated with field data

STUDY 45	
CITATION	Nasirian, A., Abbasi, B., Cheng, T. C. E., and Arashpour, M. (2022). Multiskilled Workforce Planning: A Case from the Construction Industry. Journal of Construction Engineering and Management, 148(5), 04022021.
COUNTRY/REGION	Australia
YEAR OF PUBLICATION	2022
STUDY FOCUS	Developed an optimization model to identify the most profitable multiskilled staffing and scheduling configuration for a specific production environment.
STUDY CONTEXT AND DATA SOURCE	A hypothetical experiment and an off-site bathroom-pod factory in Melbourne containing 20 tasks, 12 workstations, and 12 initially single-skilled workers. Factory observations, production records, salary data, and input from the site manager informed the model. The factory was also used in the authors' earlier studies.
METHOD/APPROACH	Integer linear optimization implemented in Julia and Gurobi. The optimal configuration was compared with no cross-training, chaining, direct capacity balancing, and random multiskilling configurations based on profit and makespan.
KEY FINDINGS	The optimal multiskilling strategy increased modeled relative profit by approximately 30% compared with the no-cross-training baseline and by more than 20% compared with the second-best staffing strategy. The optimal multiskilling strategy reduced modeled makespan by approximately 30%-33% compared with the no-cross-training baseline.
KEY LIMITATION(S)	The study used one off-site factory, estimated multiskilled operation times rather than observing them, and considered only training, salary, makespan, and cost effects.

STUDY 46	
CITATION	Tian, Y., Xiong, T., Liu, Z., Mei, Y., and Wan, L. (2022). Multi-Objective Multi-Skill Resource-Constrained Project Scheduling Problem with Skill Switches: Model and Evolutionary Approaches. Computers & Industrial Engineering, 167, 107897.
COUNTRY/REGION	Not specified; authors based in China and New Zealand
YEAR OF PUBLICATION	2022
STUDY FOCUS	Developed a multiskilled-resource scheduling model that accounts for the additional time and cost incurred when workers or resources switch between skills.
STUDY CONTEXT AND DATA SOURCE	Thirty-six iMOPSE benchmark project instances based on information-technology projects, comprising 18 instances with 100 tasks and 18 with 200 tasks. Skill-switch times were randomly generated rather than obtained from construction projects.
METHOD/APPROACH	Mixed-integer programming and a multi-objective evolution strategy incorporating a flexible solution representation, group-and-compress schedule generator, and adaptive resource-leveling operator. The proposed approach was compared with existing scheduling algorithms.
KEY FINDINGS	The study showed the importance of accounting for the time and cost of skill switching when scheduling multiskilled resources; grouping similar-skill tasks reduced unnecessary switches and improved modeled cost–duration outcomes.
KEY LIMITATION(S)	The study used benchmark data and randomly generated skill-switch times. It assumed multiskilled resources and evaluated scheduling algorithms rather than the effect of multiskilling compared with single-skilling.

STUDY 47	
CITATION	Abreu, J. P. M. de, Cardoso, G. de C., Marchiori, F. F., Brandstetter, M. C. G. de O., and Heineck, L. F. M. (2023). Multiskilled Labor Force: A Discussion of this Missing Link of Lean Construction in Brazilian Companies. Ambiente Construído, 23(4), 7–23.
COUNTRY/REGION	Brazil
YEAR OF PUBLICATION	2023
STUDY FOCUS	Examined the extent of multiskilling adoption, workforce composition, training practices, and its relationship with subcontracting in Brazilian construction companies.
STUDY CONTEXT AND DATA SOURCE	Survey responses from 191 construction professionals representing residential and commercial, industrial, and infrastructure companies in Brazil.
METHOD/APPROACH	Questionnaire survey, descriptive statistics, t-tests, correlation and regression analysis, and qualitative analysis of respondents' comments.
KEY FINDINGS	Most surveyed Brazilian construction companies employed mixed teams of specialized and multiskilled workers. Multiskilling and subcontracting were commonly used together as workforce-flexibility strategies, while larger companies tended to have a lower proportion of multiskilled workers. Respondents associated multiskilling with greater workforce flexibility, whereas companies without multiskilled workers perceived specialized labor as more productive, higher quality, and less training-intensive.
KEY LIMITATION(S)	The study relied on a self-reported survey and did not verify workers' actual skill use or assess the effects of multiskilling on project performance.

STUDY 48	
CITATION	Albalawi, R. K., Goodrum, P. M., and Taylor, T. R. B. (2023). Applying the Tier II Construction Management Strategy to Measure the Competency Level Among Single and Multiskilled Craft Professionals. Buildings, 13(5), 1175.
COUNTRY/REGION	United States
YEAR OF PUBLICATION	2023
STUDY FOCUS	Applied the Tier II workforce-management strategy to compare technical and management competency levels between single-skilled and multiskilled construction craft professionals.
STUDY CONTEXT AND DATA SOURCE	A 2020 web-based survey of 2,740 construction workers across all 50 U.S. states. The primary comparison included 980 single-skilled and 719 multiskilled craft professionals, with a separate analysis of carpenters.
METHOD/APPROACH	Tier II competency scoring, independent-samples t-tests, and multinomial logistic regression to compare competency elements and identify factors associated with higher scores.
KEY FINDINGS	Multiskilled workers had a higher average Tier II competency score than single-skilled workers—6.27 versus 5.17—and scored higher in most technical and management elements. The competency advantage associated with additional certifications appeared to diminish beyond two trades, while certification count and work experience were the strongest predictors of higher competency.
KEY LIMITATION(S)	The study relied on self-reported survey data and could not determine whether multiskilling itself led to the higher competency scores.

STUDY 49	
CITATION	Barkokebas, B., Al-Hussein, M., and Hamzeh, F. (2023). Assessment Of Digital Twins to Reassign Multiskilled Workers in Offsite Construction Based on Lean Thinking. Journal of Construction Engineering and Management, 149(1), 04022143.
COUNTRY/REGION	Canada
YEAR OF PUBLICATION	2023
STUDY FOCUS	Evaluated a digital-twin approach for dynamically reassigning multiskilled workers in offsite construction while accounting for learning, worker movement, and wage differences.
STUDY CONTEXT AND DATA SOURCE	Production data from a modular residential construction factory in Alberta, Canada, with seven workstations and 18 fixed workers. The inputs were obtained from previously developed and validated factory-production models.
METHOD/APPROACH	Hybrid discrete-event and continuous simulation, learning-curve modeling, heuristic worker reassignment, and cost sensitivity analysis. Direct capacity balancing, dual-skill, and hybrid multiskilling configurations were evaluated under different frequencies of digital-twin intervention.
KEY FINDINGS	The proposed digital-twin-managed multiskilling approach reduced modeled total production cost by approximately 25% and total production duration by approximately 40% compared with the baseline. Average waiting time per module decreased by approximately 62%, while average cycle time decreased by about 37%, depending on the multiskilling configuration and frequency of digital-twin intervention.
KEY LIMITATION(S)	The study modeled one offsite factory, and the baseline comparison combined the effects of digital-twin management and multiskilling rather than separating them.

STUDY 50	
CITATION	Li, Q., Jiang, M., Tao, S., Hao, J., and Chong, H.-Y. (2023). The Integrated Problem of Construction Project Scheduling and Multiskilled Staff Assignment with Learning Effect. Journal of Construction Engineering and Management, 149(8), 04023064.
COUNTRY/REGION	China
YEAR OF PUBLICATION	2023
STUDY FOCUS	Developed a scheduling and staffing model for assigning multiskilled workers while accounting for learning-based skill development and changing activity durations.
STUDY CONTEXT AND DATA SOURCE	A section of a hospital construction project in Jiangsu, China, comprising five activities, four workers, and three skill types, supplemented by randomly generated instances of activities.
METHOD/APPROACH	Integer linear programming solved with CPLEX and a tabu-search algorithm incorporating six worker-assignment priority strategies.
KEY FINDINGS	Project completion time was reduced by approximately 4.8%, from 21 to 20 time units, when learning effects were incorporated into the optimized multiskilled staff-assignment model.
KEY LIMITATION(S)	The study used one small project case and generated test instances, and it did not compare the multiskilled workforce with a single-skilled alternative.

STUDY 51	
CITATION	Oh, H. J., Chang, S., and Ashuri, B. (2023). Patterns Of Skill Sets for Multiskilled Laborers Based on Construction Job Advertisements Using Web Scraping and Text Analytics. Journal of Management in Engineering, 39(3), 04023009.
COUNTRY/REGION	United States
YEAR OF PUBLICATION	2023
STUDY FOCUS	Identified high-demand dual-skill combinations to guide the development of multiskilled construction workers.
STUDY CONTEXT AND DATA SOURCE	Approximately 13.7 million job-advertisement records collected from Indeed across the United States between April 2020 and May 2021, reduced to 1,415,436 unique advertisements across 19 construction occupations. The study also surveyed 47 construction professionals.
METHOD/APPROACH	Web scraping in R, keyword-based text mining, dual-skill matrices, and comparison with an industry-professional survey.
KEY FINDINGS	Job advertisements showed that desirable trade combinations varied by workers' primary trades, with plumbers/pipefitters–electricians and welders–ironworkers among the most frequent combinations. Survey respondents most strongly recommended drywall installers/ceiling tile installers/tapers–carpenters, plumbers/pipefitters–boilermakers, and HVAC mechanics/installers–electricians.
KEY LIMITATION(S)	While the study provided skill set matrices, it did not assess how the identified trade combinations affected project performance.

STUDY 52	
CITATION	Peng, J. L., Liu, X., Peng, C., and Shao, Y. (2023). Multi-Skill Resource-Constrained Multi-Modal Project Scheduling Problem Based on Hybrid Quantum Algorithm. Scientific Reports, 13, 18502.
COUNTRY/REGION	China
YEAR OF PUBLICATION	2023
STUDY FOCUS	Developed a project-scheduling model for allocating multiskilled resources across different activity-execution modes to minimize project duration.
STUDY CONTEXT AND DATA SOURCE	Adapted PSPLIB test cases containing 30, 60, 90, and 120 activities with different resource quantities, together with a continuous rigid bridge-girder project in Changsha, Hunan Province, with an original duration of 63 days.
METHOD/APPROACH	Nonlinear mathematical modeling and a hybrid quantum particle swarm optimization algorithm incorporating JAYA search and logistic chaotic mapping. The algorithm was compared with conventional particle swarm optimization and standard quantum particle swarm optimization.
KEY FINDINGS	For the bridge project, the optimized multiskilled resource and activity-mode schedule reduced the modeled project duration from 63 to 48 days, a reduction of approximately 24%.
KEY LIMITATION(S)	The study focused on algorithm-based scheduling and did not account for specific trade combinations or external project factors.

STUDY 53	
CITATION	Albalawi, R., Goodrum, P. M., and Albattah, M. A. (2024). Evolution Of Multiskilled Craft Professionals and their Level of Certification In the US Industrial Construction Sector. Journal of Management in Engineering, 40(1), 04023057.
COUNTRY/REGION	United States
YEAR OF PUBLICATION	2024
STUDY FOCUS	Examined certification patterns and exam performance among multiskilled craft professionals.
STUDY CONTEXT AND DATA SOURCE	NCCER and NCACP records for 640,726 exam takers from 2005 to 2020, covering 211 certificates grouped into 30 certification areas across 14 construction trades.
METHOD/APPROACH	Pearson correlation, hierarchical cluster analysis, binary logistic regression, and two-sample proportion tests.
KEY FINDINGS	Multiskilled workers typically achieved advanced certification in one primary trade and only basic or specialized certification in a secondary trade; industrial electrician–instrumentation technician was the strongest certification pairing. Multiskilling may be less practical for highly specialized trades such as electrical and instrumentation because of the expertise required. Years of experience were positively associated with exam pass rates across all trade groups and formal training improved pass rates in the electrical and mechanical groups.
KEY LIMITATION(S)	The study primarily relied on certification exam data and did not assess workers' onsite performance or project outcomes.

STUDY 54	
CITATION	Han, J., Chen, C., Tiong, R. L. K., and Wu, K. (2024). Smart Multi-Project Scheduling and Multi-Skilled Workforce Assignment for Prefabricated Bathroom Unit Production. Automation in Construction, 166, 105626.
COUNTRY/REGION	Singapore
YEAR OF PUBLICATION	2024
STUDY FOCUS	Developed an integrated scheduling and workforce-assignment model for managing multiskilled workers in prefabricated bathroom unit production.
STUDY CONTEXT AND DATA SOURCE	Data from an ongoing PBU project at a Singapore precast factory, including 21 production operations, observed processing times, and workforce requirements obtained through project-manager interviews. Additional scenarios covered 5–20 simultaneous projects.
METHOD/APPROACH	Two-level mixed-integer optimization model incorporating individual workers' skills, competency, learning effects, overtime, and outsourcing, solved using a hybrid whale optimization algorithm.
KEY FINDINGS	The study developed a model that assigns multiskilled workers across PBU production tasks based on their skills, competency levels, and learning effects. The proposed algorithm outperformed the comparison algorithms, and the sensitivity analysis identified a minimum efficient internal workforce level before costs and delays increased.
KEY LIMITATION(S)	Based on one PBU factory and modeled assumptions; the results did not isolate multiskilling from learning and scheduling effects and excluded worker fatigue and internal logistics.

STUDY 55	
CITATION	Mozhdehi, S., Baradaran, V., and Hosseinian, A. H. (2024). Multi-Skilled Resource-Constrained Multi-Project Scheduling Problem with Dexterity Improvement of Workforce. Automation in Construction, 162, 105360.
COUNTRY/REGION	Not specified; authors based in Iran
YEAR OF PUBLICATION	2024
STUDY FOCUS	Developed a scheduling model that assigns multiskilled workers across multiple projects while accounting for skill improvement through practice and collaboration with more proficient workers.
STUDY CONTEXT AND DATA SOURCE	Modified iMOPSE benchmark instances covering two to four simultaneous projects, together with an adapted construction case involving three buildings, 30 multiskilled workers, nine skills, and up to 150 activities per project.
METHOD/APPROACH	Mixed-integer mathematical modeling and a modified biogeography-based optimization algorithm, compared with genetic, differential evolution, imperialist competitive, particle swarm, CPM, and CPLEX approaches.
KEY FINDINGS	Average project completion time decreased from 391.6 to 320.1-time units under the proposed MBBO algorithm when worker dexterity improvement was considered, an approximate 18% reduction.
KEY LIMITATION(S)	The results were model-based and relied on modified benchmark data and one adapted case. They reflect learning within a multiskilled workforce rather than the isolated benefit of multiskilling.

STUDY 56	
CITATION	Zarei, F., Arashpour, M., Mirnezami, S.-A., Shahabi-Shahamiri, R., and Ghasemi, M. (2024). Multi-Skill Resource-Constrained Project Scheduling Problem Considering Overlapping: Fuzzy Multi-Objective Programming Approach to a Case Study. International Journal of Construction Management, 24(8), 820–833.
COUNTRY/REGION	Iran
YEAR OF PUBLICATION	2024
STUDY FOCUS	Developed a scheduling model for assigning multiskilled workers while balancing project duration, cost, and quality under uncertainty.
STUDY CONTEXT AND DATA SOURCE	A railway-bridge construction project with 32 real activities, plus two dummy activities, and benchmark instances containing 50 and 100 activities. Project inputs were provided by company managers and experts.
METHOD/APPROACH	Multi-objective mixed-integer linear programming, interval-valued fuzzy modeling, and an extended IVF-ABS optimization approach solved using GAMS/CPLEX.
KEY FINDINGS	The optimized schedule reduced the modeled project duration from the owner's 195-day deadline to 167 days, an improvement of approximately 14%. Across the selected uncertainty levels, the proposed IVF-ABS scheduling approach produced approximately 24% lower modeled project costs than the comparison methods.
KEY LIMITATION(S)	The model was based on assumptions that may not be fully achievable in real-world construction projects, such as allowing overlapping and rework for certain activities, assuming no time lag between precedence activities, and considering multi-skilled labor as always available.

STUDY 57	
CITATION	Cao, Q., Zou, X., and Zhang, L. (2025). A Flexible Scheduling Framework for Repetitive Construction Projects Based on Constraint Programming. Journal of Construction Engineering and Management, 151(7), 04025073.
COUNTRY/REGION	Not specified; authors based in China
YEAR OF PUBLICATION	2025
STUDY FOCUS	Developed a flexible scheduling framework for repetitive construction projects that can incorporate multiskilled crews alongside soft logic, multicrew operation, multimode execution, crew transfers, work interruptions, and alternative optimization objectives.
STUDY CONTEXT AND DATA SOURCE	Previously published repetitive-project cases were used to verify the framework, including a sewer-system project, a pipeline project, and a real-life housing-estate project. The sewer and pipeline cases used single-skilled crews, while the housing-estate case included five buildings, 17 apartments, 27 activities, and 14 available crews, six of which were multiskilled. No new field data were collected.
METHOD/APPROACH	Constraint programming using IBM ILOG CPLEX CP Optimizer, with the ε-constraint method applied for multiobjective optimization. The framework was compared with schedules generated by earlier optimization and scheduling methods.
KEY FINDINGS	The framework incorporated multiskilled crews and assigned them across repetitive activities under different scheduling and work-continuity constraints. In the housing-estate case, where both analyses used multiskilled crews, the framework produced a 335-day schedule compared with 385 days under an earlier algorithm. The difference reflects the scheduling method rather than an isolated multiskilling effect.
KEY LIMITATION(S)	The results were model-based and relied on previously published project data. Multiskilling was one of several scheduling features, and its independent effect was not isolated. The reported time, cost, and crew improvements therefore cannot be attributed specifically to multiskilling.

STUDY 58	
CITATION	Mai, T. P., Doan, D. T., and Ghaffarianhoseini, A. (2025). Utilizing multiskilled resources in addressing labor shortage issues in off-site construction: benefits, challenges, and best practices. Journal of Construction Engineering and Management, 151(4), 04025014.
COUNTRY/REGION	New Zealand
YEAR OF PUBLICATION	2025
STUDY FOCUS	Examined the use of multiskilled labor as a strategy for addressing skilled-labor shortages in off-site construction, with emphasis on perceived benefits, implementation challenges, and best practices.
STUDY CONTEXT AND DATA SOURCE	The study combined a systematic review of 32 papers with semi-structured interviews involving eight New Zealand off-site construction professionals. Seven of the reviewed papers directly examined multiskilling in off-site construction. Interviewees had 5–20 years of experience and had participated in between one and 15 off-site construction projects.
METHOD/APPROACH	PRISMA-based systematic literature review, semi-structured interviews, and qualitative thematic analysis. Interview findings were compared with prior literature and reviewed through member checking.
KEY FINDINGS	Interviewees associated multiskilling with improved workforce flexibility, resource allocation, efficiency, potential cost savings, and faster project completion, although these benefits were not directly measured. Effective implementation depended on identifying transferable skills, investing in training, meeting certification and industry standards, and standardizing work processes.
KEY LIMITATION(S)	The findings were based on a small qualitative sample and were limited to the New Zealand context. The study did not use project-performance records or directly measure the cost, schedule, productivity, or workforce effects of multiskilling.

STUDY 59	
CITATION	Tao, S., Yu, J., Zhu, J., Chen, S., and Li, X. (2026). Precast Component Production Scheduling Considering Outsourcing and Multiskilled Resources. Journal of Construction Engineering and Management, 152(5), 04026040.
COUNTRY/REGION	China
YEAR OF PUBLICATION	2026
STUDY FOCUS	Developed an integrated approach for precast-component production planning that jointly considered outsourcing decisions, in-house production scheduling, and the allocation of multiskilled workers.
STUDY CONTEXT AND DATA SOURCE	The study used operational records from Enterprise Z, a precast-component manufacturer in East China with two production lines and 31 employees. About 30% of the workers had skills for producing two or three component types. The dataset included 2023 demand orders, employee skill profiles, production times, labor requirements, and inventory, switching, and outsourcing costs. These data were used to create 12 benchmark instances across off-, shoulder-, and peak-season demand. The paper mentions interviews conducted during data collection but does not report the number or roles of participants.
METHOD/APPROACH	An integer linear programming model was developed to jointly optimize outsourcing, production scheduling, and multiskilled-worker allocation. CPLEX was used for smaller instances, while a customized Deep Q-network algorithm was used for larger ones. The methods were compared with random search and the company's existing empirical scheduling approach, followed by sensitivity analyses.
KEY FINDINGS	The integrated optimization approach reduced modeled total production costs by 6.6%–12.1% across the shoulder- and peak-season cases compared with the company's empirical scheduling method. The authors reported average monthly savings exceeding CNY 31,000. The modeled cost-minimizing proportion of multiskilled workers was 30% in the off-season and 80% in the shoulder and peak seasons. Costs increased slightly beyond these levels because of excess multiskilled staffing and skill redundancy. The DQN solutions were within 0.21%–1.46% of the CPLEX optimal solutions and reduced computational time by approximately 90% for most problem instances.
KEY LIMITATION(S)	The findings were based on model results rather than implementation of the proposed schedules in the factory. Because outsourcing, production sequencing, line assignment, and multiskilled-worker allocation were optimized together, the savings attributable to multiskilling alone could not be identified. The analysis also relied on data from one manufacturer and assumed fixed demand and production conditions.

Terms, Abbreviations and Definitions

Terms are defined as used in this report. Where a term is defined in the report body (multiskilling, cross-training, workforce classifications, workforce strategies, inferential testing), the wording here follows the report. Where prior studies used a term differently, the report's usage governs.

Core multiskilling terms

Term	Definition
Multiskilling	The ability of an individual worker to perform two or more distinct types of work beyond the worker's primary trade or work assignment. The additional work may involve another trade, task, work process, or, in off-site construction, a production workstation that would otherwise be assigned separately. Workers may already possess these capabilities or acquire them through cross-training.
Multiskilling (crew level)	A crew in which workers are trained or otherwise able to be reassigned across more than one distinct task or type of work. A crew is not considered multiskilled solely because it includes workers from different trades.
Cross-training	Training that enables a worker to perform one or more tasks or work processes beyond the worker's primary trade or work assignment. In this report, cross-training refers to the process used to develop additional capability, while multiskilling refers to the resulting capability or workforce arrangement.
Primary trade or work assignment	The trade, duties, task, or workstation to which a worker is primarily assigned before multiskilling is considered. Onsite, generally the worker's primary or original trade; in off-site production, the worker's primary task or assigned workstation.
Additional skill	A distinct capability that enables a worker to perform another trade activity, task, work process, production operation, or workstation assignment beyond the primary trade or work assignment.
Single-skilled worker	A worker assigned to one primary trade, skill area, task category, or workstation. Single-skilled workers were commonly used as the comparison group in prior studies.
Dual-skilled worker	A worker capable of performing work in two distinct skill areas, generally a primary skill and one additional skill.
Multiskilled worker	A worker capable of performing work across two or more distinct skills, trades, tasks, or workstations. The number of skills is not always specified in prior studies.
Multiskilled crew or team	A crew organized to complete more than one distinct type of work, with workers capable of covering or being reassigned across the crew's tasks.

Workforce strategies and training arrangements

Term	Definition
Single-skill strategy	Each worker remains assigned to one primary trade or skill area; the baseline against which multiskilling strategies were compared.
Dual-skill strategy	A workforce arrangement in which workers can perform work associated with two distinct trades or skill areas.
Four skills strategy	An arrangement in which project trades are consolidated into four broad groups: civil/structural, general support, mechanical, and electrical.
Four skills-helper strategy	The same four broad groups, but with helpers from all trades pooled into the general support group; journeymen and foremen remain within the group associated with their original trade.
Tier II strategy	A U.S. workforce-management strategy in which craft workers develop multiple craft skills along with broader planning and management capabilities, rather than remaining in a single-craft role.
Chaining	An off-site training arrangement in which workers learn to operate a secondary workstation located next to their primary station.
Direct capacity balancing	Training selected workers to support overutilized workstations or stations with recurring production bottlenecks.
Upstream and downstream training	Training that equips workers to support workstations located earlier (upstream) or later (downstream) in the production sequence.
Full cross-training	Training existing workers to operate across most or all workstations in the production process.
Hiring-based multiskilling	Meeting flexibility needs by hiring workers who already hold multiple skills, including dual-skilled workers, four-skilled workers, helper-level four-skill workers, or a small cross-trained crew that moves among bottleneck workstations.

Work settings

Term	Definition
Onsite construction	Construction work performed at the project site under field conditions, typically organized by trade.
Off-site construction (prefabrication)	Production of building components, assemblies, or modules in a factory or other controlled location before transport to the project site; typically organized as a sequence of workstations.
Workstation	A defined production operation in an off-site facility to which workers are assigned, such as framing, plumbing, electrical work, waterproofing, glazing, or painting.
Production bottleneck	The workstation or operation whose capacity limits overall production flow; a common target for reassigning multiskilled workers.

Performance and worker outcome measures

Term	Definition
Project performance outcome	A measurable effect on project delivery, production, or workforce requirements. In this review: schedule, cost, workforce requirements, and productivity. Worker outcomes are reported separately.
Project or construction duration	The time required to complete a project, modeled project, or project case; a project-level schedule measure.
Makespan	The total time required to complete a defined production sequence or set of tasks; the schedule measure most often used in off-site, prefabrication, and scheduling studies. Related terms include production completion time and production duration.
Cost measures	Prior studies measured different cost categories: labor cost, cost price, workforce allocation cost, production cost, and total project cost. A reduction in one category (such as labor cost) does not necessarily produce an equivalent reduction in total production or project cost.
Workforce requirements	The number of workers needed, demanded, or allocated to deliver the work; measured as project workforce size, required workforce, worker requirements, or workers allocated.
Labor deficit	The gap between the labor a project requires and the labor available under constrained conditions.
Labor productivity rate	Output per unit of labor input, such as units installed per labor hour. Normalizes output by the labor hours consumed, unlike throughput.
Throughput	The output of a production system per period of time, such as units produced per day. Reflects system flow and capacity rather than output per labor hour; a throughput gain can come from added labor as well as more efficient labor.
Cycle time	The time for one unit or module to move through a production process from start to finish.
Waiting time	Idle time in which a unit, module, or workstation waits for work, workers, or preceding operations to finish.
Employment duration	The length of time a worker remains employed within a project, production system, or workforce plan. Longer duration within one project does not by itself demonstrate continued employment across projects or long-term job security.

Evidence sources and study types

Term	Definition
Model-based finding	A quantified effect generated through simulation, optimization, scheduling analysis, or scenario comparison rather than measured from an implemented multiskilling arrangement on an active project. Model-based findings depend on the assumptions, constraints, and inputs used.
Simulation, optimization, scheduling, and scenario analysis	Simulation models represent a project, production system, or labor market and test how changes in labor assignment may affect outcomes. Optimization identifies the preferred assignment, crew composition, or strategy under defined constraints. Scheduling analysis examines how assignments and resource constraints affect sequencing and duration. Scenario analysis compares alternative labor-use strategies under assumed conditions.
Agent-based simulation	A simulation built from many individual agents (such as workers, crews, or firms) whose behaviors and interactions produce system-level outcomes.
Discrete-event simulation	A simulation that models a process as a sequence of events, such as task starts and finishes, to trace production flow, queues, and delays.
Digital twin	A digital replica of a physical production system that is updated with operational data and used to test decisions, such as reassigning multiskilled workers on a shop floor.
CII model plant	A model petrochemical project developed through the Construction Industry Institute, consisting of project estimates, labor-demand profiles, and expert staffing plans. Several early U.S. multiskilling analyses are based on it; it is not a constructed project.
Benchmark problem (RCPSP)	A standard resource-constrained project scheduling problem instance from a published library, used to test scheduling algorithms. Benchmark results do not come from actual construction projects.
Direct onsite field data	Direct observation or recording of work activities from active construction projects.
Head-to-head comparison	A comparison of multiskilled and single-skilled labor performing the same or closely matched work, under similar conditions, using the same performance measures.
Secondary or industry dataset	An existing structured dataset, such as certification records, exam completions, job advertisements, workforce databases, or industry labor statistics, analyzed rather than collected for the study.
Certification records (NCCER/NCACP)	Craft assessment and certification data from the National Center for Construction Education and Research's National Craft Assessment and Certification Program, used to observe which skills U.S. craft workers hold or attempt together.
Delphi panel	A structured expert-input process in which a panel answers questions in successive rounds, with feedback between rounds, to converge on a collective judgment.

Analytical methods and modeling terms

Term	Definition
Inferential statistical testing	Formal procedures for testing relationships, group differences, effects, or statistical significance, such as significance tests on regression coefficients, correlation tests, chi-square tests, paired t-tests, analysis of variance, confidence intervals, and p-values.
Descriptive quantitative analysis	Numerical summaries using counts, percentages, averages, mean scores, cross-tabulations, or before-and-after comparisons, without formal statistical testing.
Genetic algorithm	An optimization method that improves candidate solutions over successive generations using selection, crossover, and mutation, by analogy to natural evolution.
Heuristic algorithm	A practical solution method designed to produce good, though not guaranteed optimal, solutions quickly; often used for large or complex scheduling problems.
Multi-criteria decision-making (MCDM)	A family of methods that score or rank alternatives across several weighted criteria; examples include AHP, TOPSIS, and PROMETHEE.
Fuzzy optimization	Optimization in which uncertain quantities, such as activity durations, are represented as ranges or membership functions rather than exact values.
Skill affinity	The observed tendency of two skills or trades to be held, attempted, or advertised together by or for the same workers.
Learning effect	The improvement in a worker's efficiency in a skill through repetition and experience; some scheduling studies model it when assigning multiskilled staff.
Dexterity improvement	Modeled growth in workforce skill levels over time as workers perform tasks; used in multi-project scheduling research.

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