Utilising Multi-Skilled Resources in Addressing Labour Shortage Issues in Off-Site Construction: Benefits, Challenges and Best Practices

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ABSTRACT:

Although off-site construction (OSC) offers numerous advantages and is gaining market share, its widespread adoption is limited by a shortage of skilled labour. Multi-skilling is valued in OSC as a solution to this shortage, providing significant cost benefits by enhancing production line efficiency. Despite ongoing discussions about labour shortages, there has been a considerable lack of research into the global presence of OSC's multi-skilled workforce. This study employs a dual approach, integrating a systematic literature review (SLR) and semi-structured interviews, to examine the use of multi-skilled labour on addressing labour shortages and enhancing productivity in OSC projects. Interviewees from diverse backgrounds highlighted the substantial benefits of multi-skilling, including enhanced efficiency, reduced costs, and accelerated project completion. However, they emphasised the drawbacks, such as manufacturing dependency, challenges in achieving high-level multi-skills, resource management, and balancing training with project needs. The research also explores key considerations for effectively utilising multi-skilled resources, such as skills transfer, identifying transferable skills, commitment training, certification and industry standards and standardisation. It provides actionable insights for policymakers and industry stakeholders, suggesting that strategic planning and investment in training are crucial for successfully implementing multi-skilling approaches, ultimately contributing to the sector's growth and efficiency.

AUTHOR KEYWORDS: Off-site construction (OSC), Multi-skilled Labour, Labour Shortages, Benefits, Drawbacks, Key Considerations

Introduction:

Forecasted to exceed $10.5 trillion in annual revenue by 2023, the construction industry is a major global player (Businesswire, 2021). However, it has lagged in efficiency improvements compared to other sectors (Razkenari et al., 2020). Off-site construction (OSC), incorporating prefabricated components and modular units, emerges as a key innovation to boost sector productivity (Bertram et al., 2019). OSC is celebrated for its potential to improve time, cost, quality, efficiency, safety, and sustainability outcomes (Sooriyamudalige et al., 2020). Furthermore, OSC's modular structures facilitate the adoption of Industry 4.0 technologies, such as assembly lines and robotics, presenting a forward-looking approach to construction (Yang & Lu, 2023).

Despite OSC's advantages and increasing market share, its adoption is hindered by a skilled labour shortage. Studies have identified specific types of skilled workers that are in high demand and short supply within OSC projects. These include skilled workforce required to install and assemble prefabricated components and technology-driven industrialised skills (Ginigaddara et al., 2022;

Navaratnam et al., 2022). The scarcity of these skilled workers in OSC presented significant operational challenges like assembly issues, planning delays, extended preparation times, and limited production capacity (Ginigaddara et al., 2022; Pan et al., 2008; S. Saad et al., 2022). The reliance on unskilled workers and the absence of specialised training exacerbate these challenges, impacting labour productivity in OSC projects (Assaad et al., 2023). This shortage leads to increased costs, project delays, reduced quality, and a higher rate of accidents and reworks, diminishing overall construction industry productivity (Oke et al., 2018).

Multi-skilling is esteemed in OSC as a remedy to labour shortages, offering notable cost benefits by improving production line efficiency (Barkokebas et al., 2023). Unlike traditional construction, which relies on specialised trades, OSC's structured environment and standardised processes are ideal for multi-skill training (Avva & Shyam Chamberlin, 2020). However, despite frequent discussions on labour shortages, only seven articles globally in the Scopus database delve into OSC's multi-skilled workforce, highlighting a significant research gap. This research aims to fill this gap by examining the impact of multi-skilled workers on OSC productivity.

In New Zealand, the construction sector is vital, contributing NZ$16.2 billion or about 8% to the GDP in 2020, ranking it as the fourth largest industry (Rotimi et al., 2023). Despite its significance, the sector faces challenges such as its small scale, limited economies of scale, and geographical isolation, hindering innovative practices' adoption (Shahzad et al., 2022). Additionally, a housing shortage exacerbated by natural disasters puts further strain on the industry. OSC is seen as a solution to these challenges (Sutrisna et al., 2022), but its adoption is curtailed by a skilled labour shortage (Almughrabi et al., 2021; Ramesh et al., 2022). There is a gap in research on addressing labour shortages in OSC through multi-skilling in New Zealand. This research selects New Zealand as a case study to investigate the utilisation of multi-skilled resources in addressing labour shortage issues in OSC, offering potential solutions to this problem. The research objectives are: i) to investigate OSC labour scarcity; ii) to examine the use of multi-skilling in addressing labour shortage issues in OSC regarding benefits, challenges and best practices; iii) to explore other strategies for mitigating labour shortages in OSC.

This research is pivotal as it tackles the pressing issue of labour shortages in OSC, aiming to elucidate the challenges and factors fueling this problem. It evaluates the potential of multi-skilling to boost OSC project productivity, highlighting its advantages, challenges, and key integration factors. Furthermore, the research broadens its scope to identify innovative solutions beyond multi-skilling to address OSC labour shortages. By offering practical recommendations and advanced strategies for OSC project management and stakeholder collaboration, this research equips OSC professionals, construction firms, policymakers, and scholars with critical insights. This enables the application of evidence-based strategies to improve OSC project efficiency and tackle labour shortages effectively.

The research organised the results and discussion sections thematically to align with the research objectives. The first part addresses the issue of labour shortage in OSC, presenting findings from the systematic literature review, which includes a global overview of labour shortages and their impacts on OSC. It also incorporates insights from interviews, offering valuable perspectives on labour dynamics in OSC projects, the causes of skilled labour shortages, and their repercussions on these projects. The second part focuses on multi-skilled labour in OSC. This section includes results from the systematic literature review, summarising the main findings from seven papers on multi-skilled labour in OSC, and insights from interviews, highlighting the benefits, challenges and key considerations for effectively utilising multi-skilled resources. Further details on the research findings are elaborated in the further discussion section, which outlines additional measures to mitigate the OSC labour shortage. The research concludes with a discussion of its contributions and limitations, as well as directions for future research.

Research Methodology:

The research methodology adopts a dual approach, integrating a Systematic Literature Review (SLR) with semi-structured interviews. The purpose of conducting SLR is to provide a comprehensive and structured overview of existing research on a specific topic, identifying gaps, trends, and inconsistencies in the literature (Whelan et al., 2021). By systematically searching, selecting, appraising, and synthesizing relevant studies, an SLR aims to offer a rigorous and evidence-based summary of the current state of knowledge in a particular field (Rice & Drane, 2020). This method allows researchers to critically evaluate and integrate findings from multiple studies, leading to a more robust understanding of the subject matter (Alves et al., 2017). On the other hand, the objective of conducting semi-structured interviews is to gather in-depth and rich qualitative data by allowing for flexibility in questioning and enabling participants to elaborate on their responses (Singh, 2021). Semi-structured interviews are particularly useful in qualitative research as they facilitate the exploration of complex phenomena, perspectives, and experiences, providing insights that may not be captured through quantitative methods alone (Adeoye-Olatunde & Olenik, 2021). Therefore, by combining the systematic approach of an SLR with the qualitative depth of semi-structured interviews, researchers can achieve a comprehensive understanding of a research topic, bridging the gap between existing literature and real-world experiences. In this study, this combination of methods provides a comprehensive exploration of labour shortages on both a global scale and within local nuances, investigating the potential of multi-skilling to mitigate these shortages in OSC.

SLR:

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines are crucial for literature searches, enhancing systematic review reporting quality and clarity. PRISMA guidelines facilitate a structured reporting format covering the review's aims, methods, and outcomes, thereby promoting transparent and reproducible research processes (Page et al., 2021). Figure 1 summarises the data search process in this systematic review following PRISMA 2020 protocol guidelines. The data search process comprised four steps:

(i) Paper identification: Scopus database was used to capture all the relevant literature. Scopus is acknowledged as the largest global database, encompassing an extensive array of research literature across various disciplines. This includes peer-reviewed journals, conference proceedings, book series, trade publications, and patents, thereby enhancing its comprehensiveness (Zyoud et al., 2023). Furthermore, Scopus provides a broader spectrum of scientific journal publications compared to other databases, coupled with an extensive indexing system that facilitates improved access to recent publications (Manzoor et al., 2022). This database is also known for its high reputation, offering noteworthy publications from influential journals and research scholars (Srivastava & Sivaramakrishnan, 2021). The following keywords were utilised: TITLE-ABS-KEY ("Off-site construction" OR "Off-site fabrication" OR "Off-site manufacturing" OR "Off-site production" OR "Modern methods of construction" OR "Prefabricated" OR "Prefabrication" OR "Precast construction" OR "Pre-assembly" OR "Prefab" OR "Construction mass production" OR "Modularisation" OR "Modular construction" OR "Modular building" OR "Modular homes" OR "Modular integrated construction" OR "Modular homebuilding" OR "Systematic construction" OR "Industrialised construction" OR "Manufactured construction") AND (“Manpower deficit” OR “Workforce scarcity” OR “Employee insufficiency” OR “Staffing inadequacy” OR “Human resources deficiency” OR “Labour insufficiency” OR “Personnel shortage” OR “Employee shortfall” OR “Workforce shortfall” OR “Labour deficit” OR “Staff shortage” OR “Human capital deficiency” OR “Employee scarcity” OR “Labour inadequacy” OR “Staffing shortage” OR “Multi-skilling” OR “Multi-talented” OR “Multi-skilled” OR “Multi-competency” OR “Cross-training” OR “Cross-competency”). The Scopus search yielded 118 academic papers, reduced to 87 after removing duplicates and non-English manuscripts for screening.

(ii) Paper screening and elimination: Papers were screened for relevance to the study's topic and objectives by reviewing titles and abstracts, resulting in 47 papers selected for detailed evaluation.

(iii) Eligibility check and quality assessment: In the eligibility check and quality assessment, the journal titles were evaluated using the Scimago Journal & Country Rank (SJR) database. The selection criteria focused on journals ranked in the subject area of Engineering, specifically within the Construction category, and limited to those classified as Q1 or Q2 according to the SJR. Based on these stringent criteria, a total of 37 peer-reviewed papers were selected for a comprehensive full-text review.

(iv) Papers included in the research: After full-text screening, 32 papers were chosen for analysis in this research.

Semi-structured Interviews:

The interview follows a four-stage process:

(i) Interviewee recruitment: Initially, purposive sampling was utilised to select construction professionals with a minimum of five years of experience in OSC. This strategy ensured the efficient identification of relevant participants, optimising time and resources (Mari et al., 2023). Given the limited number of OSC specialists within New Zealand, the research also adopted snowball sampling to broaden the participant pool. Initial contacts were made through LinkedIn, a vast professional networking site, from which these contacts facilitated further referrals, thereby expanding the research's scope and enriching its insights through their professional networks (Albrecht, 2011; Doan et al., 2021).

(ii) Interviewing: Research on optimal sample sizes for qualitative studies indicates that saturation - the point at which no new information or themes are observed in the data - guides the determination of necessary participant numbers. Hennink et al. (2017) found that code saturation was typically reached after nine interviews. Similarly, Guest et al. (2006) observed that data saturation generally occurred between seven and 12 interviews, with most core themes emerging within the initial six discussions. Namey et al. (2016) proposed that between eight to 16 interviews may suffice, depending on the desired saturation level. In this research, saturation was reached after conducting eight interviews, aligning with the benchmarks and underscoring the efficiency of the sampling strategy employed.

The questions were structured into three sections, each containing primary questions. During the interviews, we had the flexibility to ask additional questions to further elucidate the participants' ideas.

Investigate labour scarcity difficulties in OSC

1. What is the current labour situation in OSC projects? Are there any noticeable difficulties or challenges related to labour scarcity?

2. What are the primary reasons for the shortage of skilled labour in OSC projects?

Examine the use of multi-skilling in OSC

3. What are the key advantages of adopting multi-skilling strategies in OSC?

4. On the other hand, what are some of the main challenges or limitations associated with multi-skilling in OSC?

5. What are key considerations for effectively utilising multi-skilled resources and the effects of these recommendations?

Explore additional measures aimed at addressing the labour shortage issue in OSC

6. Apart from utilizing multi-skilling labour, what are some potential measures or strategies that can be implemented to address the labour shortage in OSC?

7. How do these additional measures address the labour shortage issues in OSC?

(iii) Data analysis: The interviews were recorded, transcribed, and analysed using thematic analysis to extract insights and identify themes that resonate with findings from relevant literature. Thematic analysis is the process of integrating codes to organize findings in a structured and meaningful way. Researchers are urged to explore deeper insights by examining complex patterns and identifying differences across groups (Adeoye-Olatunde & Olenik, 2021). This approach enables the linkage of interview insights with scholarly research, facilitating a rich thematic exploration. Thematic analysis, noted for its flexibility, allows for an in-depth examination of data, providing a layered understanding of the subject matter (Maqbool & Patil, 2023). Upon thematic analysis, the research offered valuable insights into three critical themes: the effects of labour shortages on OSC productivity, the use of multi-skilling in terms of benefits, challenges and best practices, and various approaches to mitigate these shortages.

(iv) Member checking: After analysing the data, interviewees were asked to review the compiled information to ensure the accuracy and fidelity of the recorded and transcribed content. This validation step is crucial for accurately capturing participants' perspectives and lends credibility to the research findings. A consensus on the results was then pursued through collaborative discussions with the interviewees, aiming for mutual agreement on data interpretations that accurately reflect their views. The validated findings were subsequently presented in the discussion section of the study, anchoring the conclusions in the genuine insights and experiences of the participants.

Interview demographics:

The interviewees' diverse backgrounds, spanning consultancy, contracting, and property development within the construction industry, provided a rich foundation for this study. Their professional experiences vary from five to twenty years, covering a broad spectrum from small to large organisations and involvement in one to fifteen OSC projects. Table 1 illustrates the range of company sizes represented and the extent of each interviewee's participation in OSC projects, adding substantial depth to the research findings.

Results and Discussion:

The issue of labour shortage in OSC:

The construction sector globally faces significant hurdles due to labour shortages, impacting productivity and the ability to meet market demand. This section delves into the multifaceted nature of this issue.

Global overview of labour shortages:

Construction companies worldwide are grappling with the dual challenges of fulfilling market demand amidst a scarcity of skilled labour and declining productivity (Avva & Shyam Chamberlin, 2020). In Canada, the economy faces workforce shortages, with projects suffering due to difficulties in recruiting and retaining sufficient skilled workers, consequently having to depend on less-skilled labour (Karimi et al., 2018). This scenario adversely affects both project quality and productivity. Canadian Statistics data reveals that labour shortages were prevalent across all provinces during the second quarter of 2021, with the construction sector particularly affected (Haan et al., 2023).

The United States construction industry has been facing a labour shortage for over a decade, affecting the efficiency of building processes and return on investment. The aging workforce trend exacerbates these challenges, negatively influencing project efficiency, costs, timelines, and safety (Oh et al., 2023). Moreover, the industry suffers from a lack of workforce diversity, particularly gender diversity, with women making up only 4% of the skilled labour force (Ramadan et al., 2022).

According to Mohamed et al. (2017), Brexit has posed a significant threat to the UK construction industry, potentially leading to a drastic shortage of skilled and unskilled labour. The introduction of stricter immigration policies could further exacerbate recruitment challenges, impacting the industry's economic growth and its ability to meet client demands.

In Australia, a notable gap in training, especially in advanced manufacturing practices and technological innovations like Building Information Modelling, Robotics, and Artificial Intelligence, has been identified (Ding et al., 2023). This training deficiency compromises construction project performance, resulting in skill mismatches, project delays, and reliance on inexperienced workers. Addressing these gaps through upskilling employees in smart technologies is crucial.

In India, the lack of skilled engineers is a major hindrance to the construction industry's development (Hazeen Fathima & Umarani, 2023). Likewise, a study in South Africa's Gauteng province highlighted recruitment difficulties, poor decision-making, and subpar training due to a shortfall in engineering expertise as key challenges (Akinshipe et al., 2022).

New Zealand's construction industry, particularly among small-scale employers, faces reluctance to invest in recruitment and training due to high labour turnover rates, worsening the labour shortage issue (Chang-Richards et al., 2017). Workforce turnover can lead to a deficiency of employees within an organisation, adversely affecting labour productivity (Ayodele et al., 2022).

This global overview underscores the critical role labour plays in the construction industry. The shortage of skilled labour can significantly disrupt project schedules, inflate costs, and compromise work quality, highlighting the imperative need for strategic interventions to address this challenge and promote sustainable industry growth.

Impacts on OSC:

The challenge of labour shortages takes on heightened significance in the global shift towards prefabrication in the construction industry. In Australia, OSC represents a modest 3%-5% of the estimated $150 billion building industry, a stark contrast to the adoption rates in countries like Sweden (80%), the Netherlands (29%), and Japan (12-16%) (Navaratnam et al., 2022). The constraints on Australian OSC stem from skill shortages, as well as a lack of experience, knowledge, and technical standards across various aspects of design, logistics, installation, and performance, including structural integrity, fire safety, acoustics, thermal efficiency, economic viability, sustainability, and non-structural elements (Navaratnam et al., 2019). Navaratnam et al. (2022) revealed that 51% of construction practitioners encountered skilled workforce shortages in implementing prefabrication.

In the UK, the OSC sector has been increasingly recognised over the past decade as a viable approach to mitigate environmental impacts and inefficiencies in construction. The sector's growth hinges on critical factors such as the availability of skilled labour, underscoring the urgency of addressing labour shortages within the OSC industry. The emphasis on cross-disciplinary education and training is vital for successfully deploying Construction 4.0 in the UK (Taylor, 2022). A shortage of skilled workers has notably decelerated the growth pace of the UK’s OSC industry, with over half of a recent survey's respondents marking the skilled labour shortage as a major hurdle. To counter this, the Construction Leadership Council's skills workstream, in partnership with the Construction Industry Training Board, has devised a targeted action plan (Ruoheng et al., 2019).

In Malaysia, despite governmental efforts to boost OSC through tax incentives and mandates in public projects, skilled labour shortages persist as a major barrier to OSC's widespread implementation (Alawag et al., 2021). Similarly, Iran and India have high hopes for OSC to address housing issues and cultivate a skilled construction sector. Yet, research points to a critical shortage of trained personnel and experienced professionals as a significant obstacle to OSC's efficiency in these countries (Arif et al., 2012; Hashemi & Hadjri, 2014)

Globally, labour shortages pose a significant obstacle to the widespread adoption of OSC. Overcoming these shortages is essential for realizing OSC's full benefits, such as enhanced sustainability and efficiency, and promoting its extensive adoption throughout the global construction industry.

Insights from interviewees:

During the exploration of labour scarcity challenges within OSC, valuable perspectives about the labour dynamics in OSC projects were obtained from interviewees, see Figure 2.

Interviewee #1 emphasised, “OSC demands specialised factory assembly, manufacturing, and on-site installation skills”. The lack of workers with these technical skills often delays projects and diminishes quality. Furthermore, although labour might be broadly available, a prevalent perception suggests that OSC is not a preferred employment option, exacerbating labour shortages in specific contexts (#2, #6).

Interviewees #3 and #5 characterised “the labour situation in OSC projects as challenging”. They mentioned that the challenge of sourcing workers with the necessary skills, compounded by language barriers, frequently results in misunderstandings and mistakes. Interviewee #4 highlighted, “the shortage often leads to common turnover, with workers frequently transitioning from one project to another”. Such turnover disrupts project continuity, making it difficult to sustain a consistent and experienced workforce over the lifespan of a construction project (Ayodele et al., 2020).

These firsthand accounts align with existing literature, underscoring the critical impact of skill deficits on the broader adoption of prefabrication technologies across various economies (Durdyev & Ismail, 2019; Rahimian et al., 2017; Rotimi et al., 2022). Moreover, the Ministry of Business, Innovation and Employment (MBIE) has recognised the importance of overcoming language barriers among immigrant construction workers, proposing essential strategies to mitigate these challenges (MBIE, 2021). This collective insight underscores the multifaceted nature of labour shortages in OSC, highlighting the need for targeted interventions to cultivate a skilled, versatile, and stable workforce.

The interviewees shed light on specific roles within OSC that are especially affected by labour shortages. Interviewees #1, #2, and #7 highlighted the necessity for precision in OSC roles, pointing out that skilled trades such as cabinet makers, glaziers, plumbers, and electricians, which require high levels of accuracy, are particularly vulnerable to labour scarcity. Furthermore, Interviewee #3 pointed out that “trades that require specialised skills or extensive training, like electricians, plumbers, and carpenters, are more affected by labour shortages”. This trend is attributed to skilled tradespeople often establishing their own businesses, which poses challenges for their retention in the OSC sector.

An intriguing contrast to these insights emerged from a survey conducted by Rotimi et al. (2022), which found that only 23% of respondents considered practical skills as crucial and indispensable for enhancing prefabrication techniques. This discrepancy between the views of the surveyed participants and the expert opinions from the interviews underscores diverse perspectives on the significance of specialised skills in advancing prefabrication practices. Such divergence highlights the complexity of addressing labour shortages in OSC, suggesting the need for a nuanced understanding of the role of skilled trades in the prefabrication landscape.

The exploration into the root causes of skilled labour shortages and their repercussions on OSC projects elicited comprehensive insights from the interviewees. Interviewees #1 and #8 identified the ageing workforce as a critical issue, with data from the Construction Leadership Council illustrating a concerning trend: for every new individual entering the industry, four are retiring (Syed Saad et al., 2022). This results in a significant drain of experience and specialised skills crucial for OSC, exacerbating the challenge of replacing talent proficient in these niche areas.

Furthermore, the absence of training programs specifically designed for OSC was highlighted (#4, #7), indicating a substantial knowledge gap. Traditional construction skills do not directly translate to OSC methodologies, a point supported by research citing the lack of skilled workers and appropriate educational frameworks (Gumusburun Ayalp & Ay, 2021; Kordestani Ghalenoei et al., 2022)

Interviewees #2 and #6 discussed the perception issues surrounding OSC, “the prevalence of OSC as a secondary option”, which aligns with the observations made by Ginigaddara et al. (2022). This perception, combined with the significant time investment required to develop specialised skills and the scarcity of multi-skilled labour, exacerbates the shortage. The resulting labour scarcity leads to wage inflation and elongated project timelines, inflating overall construction costs and complicating project management, particularly for those overseeing multiple projects.

Additionally, interviewee #3 pointed to "visa regulations as a significant factor exacerbating labour scarcity". The ripple effects of such shortages are far-reaching, causing delays, escalating costs, and challenges in adhering to project schedules, thereby adversely affecting project efficiency and delivery.

Table 2 presents a comprehensive summary of the key reasons and impacts identified from both the literature review and semi-structured interviews. These collective insights paint a detailed picture of the complex challenges posed by labour scarcity in OSC projects. The issues range from the need for specialised skills and industry perceptions to regulatory barriers, all contributing to the nuanced landscape of labour shortages in OSC and underscoring the urgency of addressing these multifaceted challenges.

Multi-skilled Labour in OSC:

Literature review on multi-skilling in OSC:

Previous research has established that a workforce equipped with diverse skill sets significantly contributes to the flexibility of production systems, allowing for a more adaptable distribution of tasks and an increased rate of production throughput (Wongwai & Malaikrisanachalee, 2011). However, a search within the Scopus database reveals that only seven articles directly address the concept of multi-skilling within the OSC context, highlighting a notable gap in the literature.

Table 3 presents a summary of the literature review on the benefits, challenges, and best practices in managing multi-skilled labour within OSC. Barkokebas et al. (2023) advocated adopting Digital Twins technology within a virtual reality framework to manage multi-skilled workforces in OSC effectively. This approach aims to counterbalance the variability introduced by custom products and manual tasks in OSC manufacturing settings. Despite the complexities involved in cross-training or the uncertainties linked to the duration of manual operations, implementing Digital Twins has shown promising outcomes for enhancing OSC manufacturing processes. The research offers a novel perspective by illustrating how the dynamic reassignment of multi-skilled workers, facilitated through comprehensive data acquisition, transformation, and application strategies, can significantly improve labour flexibility on OSC production floors.

Nasirian, Arashpour, Abbasi, Zavadskas, et al. (2019) explored the operational benefits of employing varied labour skill set configurations to address production bottlenecks in OSC. The case study centred on a Melbourne, Australia-based modular factory specialising in producing bathroom pods. The researchers proposed that multi-skilling and cross-training construction resources could serve as a cost-effective solution to these challenges. The research adopted a hybrid research methodology combining optimisation and multi-criteria decision-making approaches to assess the impact of different labour skill set configurations on performance metrics. It evaluated and prioritised various multi-skilling policies and examined scenarios where the rankings of these policies might change. Notably, the research found that training strategy preferences were predominantly determined by the number of multi-skilled workers rather than their specific placement within the prefabrication process.

Goh and Goh (2019) conducted a research at a Singaporean site utilising prefabricated prefinished volumetric construction, a form of modular construction. Their approach to enhancing efficiency included applying Total Quality Management to reduce errors, implementing an Internet-based E-Kanban system to improve distribution efficiency, and adopting Construction Robotics for labour automation. Additionally, they advocated for cross-training to reduce idle resource time. The findings suggested that these strategies could lead to significant operational improvements. Compared to a baseline modelling framework, the site experienced a reduction of up to 81.27% in operational and processing times, a 17.91% increase in resource productivity, and up to a 74.30% decrease in work-in-progress levels through the automation of construction processes. These outcomes underscore the potential benefits of adopting OSC methodologies, highlighting the pivotal role of integrating advanced technologies and training strategies to enhance efficiency and productivity in construction.

Nasirian, Arashpour, Abbasi and Akbarnezhad (2019) developed an optimisation model through mathematical simulation to efficiently allocate cross-skilled workers to appropriate roles within OSC project timelines. This research demonstrated that creating an effective resource management strategy is crucially influenced by the operational context, with variations in constraints and variability playing key roles in developing tailored recommendations. It emphasised the importance of assessing resource planning strategies under various scenarios, illustrating that hiring multi-skilled workers is an effective approach to reducing overall project timelines.

Arashpour, Kamat, et al. (2018) capitalised on manufacturing data from modular construction projects in Brisbane and Melbourne, Australia, to examine the costs and time implications associated with cross-skilling employees for workforce planning. The research aimed to reduce the expenses linked to deploying cross-trained personnel in OSC by employing integer programming and stochastic modelling, thus enhancing cost-efficiency in workforce utilisation.

Arashpour, Wakefield, et al. (2018) advocated for integrating processes and developing a multi-skilled workforce as solutions to the challenges OSC faces, such as excessive costs, inefficiencies, and safety risks. By analysing production data from three off-site fabricators, the research identified the most effective process integration strategies, recommending reallocating excess capacity from underutilised to overburdened resources through direct or indirect methods.

Arashpour et al. (2015) examined and compared various cross-training strategies to foster a workforce proficient in multiple skills within OSC. By determining the optimal mix of additional skills and executing

1080 computer-simulated scenarios with data from two Australian factories, the study utilised quantifiable performance metrics to assess different process integration models and the employment of multi-skilled labour. The findings indicated that the ideal design of process integration frameworks is significantly influenced by the level of capacity imbalance and the variability in production times, offering valuable insights for optimising labour efficiency in OSC environments.

Insights from interviews on multi-skilling in OSC:

Through interviews, the nuanced perspectives on adopting multi-skilling in OSC were explored, highlighting its benefits and challenges. All interviewees concurred on the effectiveness of multi-skilling in enhancing efficiency, reducing costs, and saving time. However, they also acknowledged that certain challenges and limitations arise with its implementation. Table 4 summarises the results derived from interviews and validated through a triangulation method using supporting literature.

Interviewees highlighted the benefits of multi-skilled workers, emphasising their ability to smoothly switch between tasks, reducing the need for task-specific specialists (#1, #6). This flexibility enhances resource allocation efficiency and has the potential to lower costs and compress project timelines. Interviewee #5 highlighted, "when workers possess multiple skills, resources can be more effectively allocated to balance variations in project demand, thus mitigating potential negative impacts on project timelines, quality, and costs". This sentiment was echoed by interviewees #3 and #8, who noted, "multi-skilling enhances efficiency, enabling individuals to manage multiple tasks simultaneously", a benefit that becomes invaluable during labour shortages and can significantly hasten project completion.

The construction sector showcases a variety of cross-training models designed to achieve diverse productivity gains, including reduced project costs, faster completion times, and improved product and service quality, as documented in the literature (Nasirian et al., 2022). Gouda et al. (2017) suggested that cost savings are possible by reducing the workforce size by deploying fewer workers who are proficient in multiple skills instead of a larger team of singly skilled workers. Moreover, Arashpour et al. (2015) demonstrated that time efficiency can be achieved by optimally reallocating resources between underutilised workstations and those facing high demand. This strategic distribution of multi-skilled labour across various project stages and demands underscores the transformative potential of multi-skilling in OSC, offering a pathway to more agile, cost-effective, and time-efficient project execution, albeit with considerations for the inherent challenges in its application.

However, the applicability of multi-skilling varies across tasks. Interviewee #5 noted, "the benefits of multi-skilling depend on the type of construction or manufacturing involved". Multi-skilling shows pronounced efficiency when it leverages similar or transferable skills within the same development or manufacturing process. This strategy reduces the need for hyper-specialisation and fosters skill transferability, thereby boosting overall productivity (Zahedi & Lu, 2022). Interviewee #2 highlighted a critical nuance: "while low-level multi-skilling demonstrates efficacy, achieving high-level multi-skilling with the necessary certifications can be time-consuming and costly". Furthermore, Interviewee #4 emphasised, "this approach requires identifying individuals capable of excelling in multiple roles, making resource management and training programs crucial".

The successful deployment of multi-skilling hinges on careful planning and robust training initiatives (#3, #7). This perspective is reinforced by Chen et al. (2022), who observed that in assembly manufacturing processes, the efficacy of workers is greatly influenced by the depth of their skill sets, which in turn depends on their experiences and the quality and regularity of training and upskilling activities. Hence, multi-skilling demands significant investment in extensive training programs. Navigating the equilibrium between training needs and project demands presents a significant financial challenge (#1, #8). as training costs encompass fees for multiple training programs and potentially higher wages for more skilled employees, leading to increased project costs (Nasirian et al., 2022). The investment in workforce training encompasses not only the enrollment fees for a variety of training programs but also the implications of higher wages for employees who attain advanced skill levels. As workers enhance their capabilities and qualifications, their value in the labour market increases, potentially leading to higher salary expectations. This escalation in personnel costs is a critical consideration for organizations aiming to implement multi-skilling strategies effectively, as detailed by Nasirian et al. (2022).

The interviews around multi-skilling in OSC projects illuminated both its merits and limitations. Interviewees acknowledged its benefits, including enhanced efficiency, improved resource utilisation, and the potential for cost savings. Multi-skilled workers enable smoother transitions between tasks and are pivotal in mitigating labour shortages, contributing to faster project delivery. Yet, the utility of multi-skilling is influenced by the specific type of manufacturing or construction and the transferability of skills within those processes. Although it can elevate efficiency, achieving advanced multi-skilling with the necessary certifications is a lengthy and costly endeavour. Identifying suitable candidates and aligning training requirements with project timelines are critical factors. The necessity for substantial investment in training is evident, albeit with the understanding that it may lead to increased expenses due to training fees and higher salaries for skilled personnel. Thus, while multi-skilling presents clear advantages for OSC, it necessitates deliberate planning and investment to harness its full potential effectively.

Therefore, interviewees discussed several key considerations for effectively utilising multi-skilled resources when implementing multi-skilling practices in OSC and the effects of these recommendations, see Figure 3. Interviewees #1 and #2 highlighted that the successful application of multi-skilling in OSC largely depends on effective skills transfer within the manufacturing process. Multi-skilling facilitates the movement of competencies from one task or role to another, underscoring the necessity of pinpointing skills that can be seamlessly transferred. Identifying overlaps or commonalities in skills enables employees to transition between different functions without extensive retraining, thus bolstering flexibility and adaptability in operations (Lin et al., 2020). Moreover, Interviewee #3 stated, “a strong commitment to training and development is a fundamental aspect of a successful multi-skilling strategy". This commitment entails investing in programs designed to equip employees with a broad range of competencies, ensuring they can perform diverse tasks efficiently. This view aligns with Perera et al. (2022), who advocate for regular training and upskilling to maintain employee competency in their multi-skilled roles. Further emphasising the importance of formal qualifications, Interviewees #4 and #6 discussed the necessity of adhering to industry standards and acquiring the requisite certifications for skills deployed in multi-skilling. To achieve operational efficiency and consistency, standardisation of processes and products is crucial (#5, #8). Establishing clear guidelines and procedures reduces ambiguity and errors, facilitating the effective performance of multi-skilled employees (Anastasiades et al., 2021).

Further Discussion:

The lack of research on multi-skilled labour in OSC, despite its potential benefits and ongoing discussions about labour shortages, can be attributed to several factors. The traditional reliance on specialised trades in construction may overshadow the exploration of multi-skilling approaches in OSC, despite their potential advantages (Ho, 2016). Bajjou and Chafi (2020) also stated that the scarcity of empirical data and case studies on successful multi-skilling implementation in OSC may hinder research efforts in this area. Additionally, researching multi-skilling in OSC requires an interdisciplinary approach, involving construction management, human resource development, and industrial engineering, which may contribute to the limited research in this area (Hussain et al., 2020). This lack underscores the necessity for research on the use of multi-skilled resources in terms of benefits, challenges and best pracices to improve productivity, and effectively mitigate labour shortages. As such, it furnishes invaluable insights for both companies and policymakers in adopting multi-skilling in OSC.

The research further discusses additional strategies to address labour scarcity issues, providing a more comprehensive view of solutions beyond multi-skilled resources. All interviewees recommended investment in targeted skills development and establishing trade academies to bridge the gap between conventional and contemporary construction techniques. They also proposed the creation of formal apprenticeship programs to offer practical experience and mentorship to novices. Interviewees #2 and #7 pointed to the importance of promoting OSC as an attractive career path and the potential benefits of recruiting international talent, aligning with recent policy changes by New Zealand Immigration aimed at drawing skilled workers from abroad (ConsultANZ, 2023). These policy updates recognise the construction sector's potential to benefit from global expertise, particularly in OSC. Additionally, enhancing collaboration between industry and educational institutions was identified as a key strategy (#3), resonating with Shahzad et al. (2023). They highlighted the critical need for skills in designing, manufacturing, and integrating OSC supply chains, underscoring the value of partnerships between academia and the construction industry. Such collaborations can ensure that the workforce is adequately prepared with the necessary skills and knowledge to tackle labour shortages and elevate the overall proficiency of individuals engaged in OSC projects.

Theoretically, this research advances the understanding of multi-skilling within OSC, highlighting the benefits and challenges of adopting multi-skilling in OSC. Practically, the findings provide actionable insights for construction firms, emphasising the need for comprehensive training and adherence to industry standards to mitigate labour shortages. Policy-wise, the research supports the development of targeted initiatives by policymakers, such as establishing trade academies and formal apprenticeship programs, and promoting international recruitment. These contributions collectively aim to enhance the utilisation of multi-skilled resources, address labour scarcity, and ultimately improve the efficiency and effectiveness of OSC projects, aligning with the research objectives of examining multi-skilling strategies and exploring additional mitigation approaches.

A limitation of this research pertains to its geographical focus on New Zealand, which may restrict the applicability of its findings to other countries without considering local differences. Future research should prioritise the development of training program frameworks to support effective multi-skilling in OSC. Such research will be crucial in evaluating the impact of training on project success and guiding the creation of robust strategies for workforce development in the OSC sector.

To visually encapsulate the key findings of this research, Figure 4 below provides a comprehensive overview of the primary results.

Conclusion:

Labour shortages significantly impact OSC project productivity. This research explores the utilisation of multi-skilled labour in addressing the labour shortages issues, aiming to improve efficiency and reduce time and costs.. Insights were gathered through semi-structured interviews with diverse construction professionals, offering a comprehensive view of the sector's challenges and opportunities.

The findings from the interviews identified several factors contributing to the skilled labour shortage in OSC projects. An ageing workforce and the resulting loss of expertise and a lack of specialised training programs for OSC create significant barriers to transitioning traditional construction skills to off-site methods. Perceptions of OSC as a less preferred career path, the extensive time required to develop specialised skills, and the scarcity of multi-skilled workers exacerbate these challenges. Visa regulations also emerged as a crucial factor complicating labour shortages, leading to project delays, increased costs, and inefficiencies.

Despite these challenges, there is a consensus among interviewees on the advantages of multi-skilling, including improved efficiency, better resource allocation, cost savings, and quicker project completion. However, implementing multi-skilling is not universally applicable, and its effectiveness varies depending on the specific manufacturing or construction process. High-level multi-skilling, while beneficial, demands substantial time and financial investment in training.

Interviewees emphasised key considerations for effectively utilising multi-skilled resources in OSC. Success hinges on efficient skills transfer, identifying overlaps in competencies, and maintaining a commitment to training and development. Adhering to industry standards, standardising processes, and establishing clear guidelines are also essential for operational efficiency and consistency in multi-skilled roles.

To combat labour shortages, the interviewees suggested several measures, such as targeted skills development, establishing trade academies, creating formal apprenticeship programs, promoting OSC as a career choice, attracting international talent, and enhancing industry-education collaboration.

In summary, this research has significantly contributed to the existing body of knowledge in two main areas. Firstly, it is the pioneering study that provides valuable insights into the use of multi-skilled labour in New Zealand, focusing on its impacts, challenges and best practices. Secondly, it explored potential strategies to address the labour shortage, aiming to enhance productivity and efficiency in OSC projects. The findings are beneficial for companies and policymakers, as they underscore the advantages, challenges, and best practices associated with multi-skilling, thereby aiding strategic decision-making and the creation of effective multi-skilling implementation frameworks. Furthermore, the research and its outcomes offer new perspectives for academia, encouraging the development of additional practices and further studies in an area that typically receives limited attention from academic researchers.

Data Availability Statement:

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request (interview data).

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References:

Adeoye-Olatunde, O. A., & Olenik, N. L. (2021). Research and scholarly methods: Semi-structured interviews. *Journal of the American College of Clinical Pharmacy, 4*(10), 1358-1367. https://doi.org/10.1002/jac5.1441

Akinshipe, O., Akinradewo, O., Aigbavboa, C., Maake, M., & Thwala, D. (2022). Engineering skills shortage: A bane to better performance in the construction industry. *AIP Conference Proceedings, 2437*. https://doi.org/10.1063/5.0092364

Alawag, A. M. M., Alaloul, W. S., Liew, M. S., Al-Bared, M. A. M., Zawawi, N. A. W. A., & Ammad, S. (2021). The implementation of the industrialized building system in the Malaysian construction industry—A comprehensive review. *Lecture Notes in Mechanical Engineering*, 3-16. https://doi.org/10.1007/978-981-16-0742-4_1

Albrecht, W. D. (2011). LinkedIn for accounting and business students. *American Journal of Business Education (AJBE), 4*(10), 39-42. https://doi.org/10.19030/ajbe.v4i10.6062

Almughrabi, F. M., Samarasinghe, D. A. S., & Rotimi, F. E. (2021). Analysis of skill shortages in prefabricated residential construction: A case for New Zealand. *Proceedings of the 37th Annual ARCOM Conference, ARCOM 2021*, 481-490.

Alves, M. F. R., Alves, A. F. R., Júnior, H. A. d. S., & Galina, S. V. R. (2017). Cognition in organizational routines research: A systematic review. https://doi.org/10.5151/enei2017-22

Anastasiades, K., Goffin, J., Rinke, M., Buyle, M., Audenaert, A., & Blom, J. (2021). Standardisation: An essential enabler for the circular reuse of construction components? A trajectory for a cleaner European construction industry. *Journal of Cleaner Production, 298*, 126864. https://doi.org/10.1016/j.jclepro.2021.126864

Arashpour, M., Kamat, V., Bai, Y., Wakefield, R., & Abbasi, B. (2018). Optimization modeling of multi-skilled resources in prefabrication: Theorizing cost analysis of process integration in off-site construction. *Automation in Construction, 95*, 1-9. https://doi.org/10.1016/j.autcon.2018.07.027

Arashpour, M., Wakefield, R., Abbasi, B., Arashpour, M., & Hosseini, R. (2018). 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. https://doi.org/10.1080/17452007.2017.1302406

Arashpour, M., Wakefield, R., Blismas, N., & Minas, J. (2015). Optimization of process integration and multi-skilled resource utilization in off-site construction. *Automation in Construction, 50*, 72-80. https://doi.org/10.1016/j.autcon.2014.12.002

Arif, M., Bendi, D., Sawhney, A., & Iyer, K. (2012). State of offsite construction in India-drivers and barriers. *Journal of Physics: Conference Series, 364*(1), 012109. https://doi.org/10.1088/1742-6596/364/1/012109

Assaad, R. H., El-Adaway, I. H., Hastak, M., & Lascola Needy, K. (2023). Key factors affecting labor productivity in offsite construction projects. *Journal of Construction Engineering and Management, 149*(1). https://doi.org/10.1061/JCEMD4.COENG-12654

Avva, V. S. R., & Shyam Chamberlin, K. (2020). Multi-skilling and crosstraining of labor in prefabrication construction industry by MCDM method. *Materials Today: Proceedings, 33*, 620-625. https://doi.org/10.1016/j.matpr.2020.05.605

Ayodele, O. A., Chang-Richards, A., & González, V. (2020). Factors affecting workforce turnover in the construction sector: A systematic review. *Journal of Construction Engineering and Management, 146*(2), 03119010. https://doi.org/10.1061/(ASCE)CO.1943-7862.000172

Ayodele, O. A., Chang-Richards, Y., & González, V. A. (2022). A framework for addressing construction labour turnover in New Zealand. *Engineering, Construction and Architectural Management, 29*(2), 601-618. https://doi.org/10.1108/ECAM-05-2020-0358

Bajjou, M. S., & Chafi, A. (2020). Lean construction and simulation for performance improvement: A case study of reinforcement process. *International Journal of Productivity and Performance Management, 70*(2), 459-487. https://doi.org/10.1108/ijppm-06-2019-0309

Barkokebas, B., Al-Hussein, M., & 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). https://doi.org/10.1061/(ASCE)CO.1943-7862.0002420

Bertram, N., Fuchs, S., Mischke, J., Palter, R., Strube, G., & Woetzel, J. (2019). Modular construction: From projects to products. *McKinsey & Company: Capital Projects & Infrastructure*, 1-34.

Businesswire. (2021). *Global construction industry report 2021: $10.5 trillion growth opportunities by 2023*. https://www.businesswire.com/news/home/20210111005587/en/Global-Construction-Industry-Report-2021-10.5-Trillion-Growth-Opportunities-by-2023---ResearchAndMarkets.com

Chang-Richards, Y., Wilkinson, S., Seville, E., & Brunsdon, D. (2017). An organizational capability framework for earthquake recovery. *Earthquake Spectra, 33*(4), 1257-1278. https://doi.org/10.1193/092515EQS142M

Chen, J. C., Chen, Y.-Y., Chen, T.-L., & Lin, Y.-H. (2022). Multi-project scheduling with multi-skilled workforce assignment considering uncertainty and learning effect for large-scale equipment manufacturer. *Computers & Industrial Engineering, 169*, 108240. https://doi.org/10.1016/j.cie.2022.108240

ConsultANZ. (2023). The New Zealand Government has announced changes to the Skilled Migrant Category and will extend the duration of the Accredited Employer Work Visa (AEWV) from three to five years in November 2023. https://www.consultanz.com.au/nz-skilled-migrants-residence/

Ding, M. J., Jie, F., Sisombat, S., & Bandlamudi, B. S. (2023). Impact of the skill shortage on the construction supply chain performance in Australia. *Civil Engineering Journal (Iran), 9*(2), 356-371. https://doi.org/10.28991/CEJ-2023-09-02-08

Doan, D. T., GhaffarianHoseini, A., Naismith, N., Ghaffarianhoseini, A., Zhang, T., & Tookey, J. (2021). Examining critical perspectives on Building Information Modelling (BIM) adoption in New Zealand. *Smart and Sustainable Built Environment, 10*(4), 594-615. https://doi.org/10.1108/SASBE-04-2020-0043

Durdyev, S., & Ismail, S. (2019). Offsite manufacturing in the construction industry for productivity improvement. *Engineering Management Journal, 31*(1), 35-46. https://doi.org/10.1080/10429247.2018.1522566

Ginigaddara, B., Perera, S., Feng, Y., & Rahnamayiezekavat, P. (2022). Offsite construction skills evolution: An Australian case study. *Construction Innovation, 22*(1), 41-56. https://doi.org/10.1108/CI-10-2019-0109

Goh, M., & Goh, Y. M. (2019). Lean production theory-based simulation of modular construction processes. *Automation in Construction, 101*, 227-244. https://doi.org/10.1016/j.autcon.2018.12.017

Gouda, A., Hosny, O., & Nassar, K. (2017). Optimal crew routing for linear repetitive projects using graph theory. *Automation in Construction, 81*, 411-421. https://doi.org/10.1016/j.autcon.2017.03.007

Guest, G., Bunce, A., & Johnson, L. (2006). How many interviews are enough? An experiment with data saturation and variability. *Field Methods, 18*(1), 59-82. https://doi.org/10.1177/1525822X05279903

Gumusburun Ayalp, G., & Ay, I. (2021). Model validation of factors limiting the use of prefabricated construction systems in Turkey. *Engineering, Construction and Architectural Management, 28*(9), 2610-2636. https://doi.org/10.1108/ECAM-04-2020-0248

Haan, M., Jin, H., & Paul, T. (2023). The mobility of construction workers in Canada: Insights from administrative data. *Applied Spatial Analysis and Policy, 16*(1), 91-118. https://doi.org/10.1007/s12061-022-09445-3

Hashemi, A., & Hadjri, K. (2014). Offsite construction, a potential answer to the Iranian housing shortages. *Proceedings of the Construction Technology and Management (CTM 2014) International Scientific Conference, Bratislava, Slovakia, 911*.

Hazeen Fathima, M., & Umarani, C. (2023). Fairness in human resource management practices and engineers' intention to stay in Indian construction firms. *Employee Relations, 45*(1), 156-171. https://doi.org/10.1108/ER-07-2021-0308

Hennink, M. M., Kaiser, B. N., & Marconi, V. C. (2017). Code saturation versus meaning saturation: How many interviews are enough? *Qualitative Health Research, 27*(4), 591-608. https://doi.org/10.1177/1049732316665344

Ho, P. H. K. (2016). Labour and skill shortages in Hong Kong's construction industry. *Engineering Construction & Architectural Management, 23*(4), 533-550. https://doi.org/10.1108/ecam-12-2014-0165

Hussain, S., Wang, X., & Hussain, T. (2020). Impact of skilled and unskilled labor on project performance using structural equation modeling approach. *Sage Open, 10*(1), 215824402091459. https://doi.org/10.1177/2158244020914590

Karimi, H., Taylor, T. R. B., Dadi, G. B., Goodrum, P. M., & Srinivasan, C. (2018). Impact of skilled labor availability on construction project cost performance. *Journal of Construction Engineering and Management, 144*(7). https://doi.org/10.1061/(ASCE)CO.1943-7862.0001512

Kordestani Ghalenoei, N., Babaeian Jelodar, M., Paes, D., & Sutrisna, M. (2022). Challenges of offsite construction and BIM implementation: Providing a framework for integration in New Zealand. *Smart and Sustainable Built Environment*. https://doi.org/10.1108/SASBE-07-2022-0139

Lin, J., Liu, H. L., Xue, B., Zhang, M., & Gu, F. (2020). Multiobjective multitasking optimization based on incremental learning. *IEEE Transactions on Evolutionary Computation, 24*(5), 824-838. https://doi.org/10.1109/TEVC.2019.2962747

Manzoor, B., Othman, I., Sadowska, B., & Sarosiek, W. (2022). Zero-energy buildings and energy efficiency towards sustainability: A bibliometric review and a case study. *Applied Sciences, 12*(4), 2136. https://doi.org/10.3390/app12042136

Maqbool, R., & Patil, K. (2023). UK construction industry standing in the COVID-19 era: Understanding the impacts on projects. *Journal of Urban Planning and Development, 149*(3). https://doi.org/10.1061/JUPDDM.UPENG-4093

Mari, T., Liew, J., & Ng, V. (2023). Re-establishing traditional stilt structures in contemporary architecture–The possibilities. *International Journal of Architectural Research: Archnet-IJAR, 17*(1), 88-108. https://doi.org/10.1108/ARCH-12-2021-0353

MBIE. (2021). *Construction sector community research – Audience and communication channels*. https://www.mbie.govt.nz/dmsdocument/25201-construction-sector-community-research-audience-and-communication-channels

Mohamed, M., Pärn, E. A., & Edwards, D. J. (2017). Brexit: measuring the impact upon skilled labour in the UK construction industry. *International Journal of Building Pathology and Adaptation, 35*(3), 264-279. https://doi.org/10.1108/IJBPA-05-2017-0023

Namey, E., Guest, G., McKenna, K., & Chen, M. (2016). Evaluating bang for the buck: A cost-effectiveness comparison between individual interviews and focus groups based on thematic saturation levels. *American Journal of Evaluation, 37*(3), 425-440. https://doi.org/10.1177/1098214016630406

Nasirian, A., Abbasi, B., Cheng, T. C. E., & Arashpour, M. (2022). Multiskilled workforce planning: A case from the construction Industry. *Journal of Construction Engineering and Management, 148*(5), 04022021. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002279

Nasirian, A., Arashpour, M., Abbasi, B., & Akbarnezhad, A. (2019). Optimal work assignment to multiskilled resources in prefabricated construction. *Journal of Construction Engineering and Management, 145*(4). https://doi.org/10.1061/(ASCE)CO.1943-7862.0001627

Nasirian, A., Arashpour, M., Abbasi, B., Zavadskas, E. K., & Akbarnezhad, A. (2019). Skill set configuration in prefabricated construction: Hybrid optimization and multicriteria decision-making approach. *Journal of Construction Engineering and Management, 145*(9). https://doi.org/10.1061/(ASCE)CO.1943-7862.0001677

Navaratnam, S., Ngo, T., Gunawardena, T., & Henderson, D. (2019). Performance review of prefabricated building systems and future research in Australia. *Buildings, 9*(2). https://doi.org/10.3390/buildings9020038

Navaratnam, S., Satheeskumar, A., Zhang, G., Nguyen, K., Venkatesan, S., & Poologanathan, K. (2022). The challenges confronting the growth of sustainable prefabricated building construction in Australia: Construction industry views. *Journal of Building Engineering, 48*. https://doi.org/10.1016/j.jobe.2021.103935

Oh, H. J., Chang, S., & 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). https://doi.org/10.1061/JMENEA.MEENG-5243

Oke, A., Aigbavboa, C., & Khangale, T. (2018). Effect of skills shortage on sustainable construction. Advances in Human Factors, Sustainable Urban Planning and Infrastructure, Cham.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., McGuinness, L. A., Stewart, L. A., Thomas, J., Tricco, A. C., Welch, V. A., Whiting, P., & Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *International Journal of Surgery, 88*, 105906. https://doi.org/10.1016/j.ijsu.2021.105906

Pan, W., Gibb, A. G. F., & Dainty, A. R. J. (2008). Leading UK housebuilders' utilization of offsite construction methods. *Building Research and Information, 36*(1), 56-67. https://doi.org/10.1080/09613210701204013

Perera, S., Ginigaddara, B., Feng, Y., & Rahnamayiezekavat, P. (2022). The new generation of construction skills: Transition from onsite to offsite. In *Innovation in Construction: A Practical Guide to Transforming the Construction Industry* (pp. 429-446). Springer. https://doi.org/10.1007/978-3-030-95798-8_17

Rahimian, F. P., Goulding, J., Akintoye, A., & Kolo, S. (2017). Review of motivations, success factors, and barriers to the adoption of offsite manufacturing in Nigeria. *Procedia Engineering, 196*, 512-519. https://doi.org/10.1016/j.proeng.2017.07.232

Ramadan, B. A., Taylor, T. R. B., Real, K. J., & Goodrum, P. (2022). The construction industry from the perspective of the workers' social experience. *Construction Research Congress 2022: Health and Safety, Workforce, and Education - Selected Papers from Construction Research Congress 2022, 4-D*, 611-621. https://doi.org/10.1061/9780784483985.062

Ramesh, S., Shahzad, W., & Sutrisna, M. (2022, 2022/11/01). Transaction cost of offsite construction (OSC): A New Zealand study. *IOP Conference Series: Earth and Environmental Science, 1101*(4), 042044. https://doi.org/10.1088/1755-1315/1101/4/042044

Razkenari, M., Fenner, A., Shojaei, A., Hakim, H., & Kibert, C. (2020). Perceptions of offsite construction in the United States: An investigation of current practices. *Journal of Building Engineering, 29*. https://doi.org/10.1016/j.jobe.2019.101138

Rice, L. B., & Drane, M. (2020). Indicators of healthy architecture—a systematic literature review. *Journal of Urban Health, 97*(6), 899-911. https://doi.org/10.1007/s11524-020-00469-z

Rotimi, F. E., Almughrabi, F. M., Samarasinghe, D. A. S., & Silva, C. (2022). Specific skill requirements within prefabricated residential construction: Stakeholders' perspectives. *Buildings, 12*(1). https://doi.org/10.3390/buildings12010043

Rotimi, J. O. B., Ramanayaka, C. D. E., Olatunji, O. A., & Rotimi, F. E. (2023). Migrant construction workers' demography and job satisfaction: a New Zealand study. *Engineering, Construction and Architectural Management, 30*(3), 1122-1145. https://doi.org/10.1108/ECAM-05-2021-0457

Ruoheng, Z., J, Z. A. S., Saeed, T., & Jennifer, W. (2019). Long-standing themes and new developments in offsite construction: The case of UK housing. *Proceedings of the Institution of Civil Engineers - Civil Engineering, 172*(6), 29-35. https://doi.org/10.1680/jcien.19.00011

Saad, S., Alaloul, W. S., Ammad, S., & Qureshi, A. H. (2022). A qualitative conceptual framework to tackle skill shortages in offsite construction industry: A scientometric approach. *Engineering, Construction and Architectural Management, 29*(10), 3917-3947. https://doi.org/10.1108/ECAM-04-2021-0287

Saad, S., Alaloul, W. S., Ammad, S., & Qureshi, A. H. (2022). A qualitative conceptual framework to tackle skill shortages in offsite construction industry: A scientometric approach. *Engineering, Construction and Architectural Management, 29*(10), 3917-3947. https://doi.org/10.1108/ECAM-04-2021-0287

Shahzad, W. M., Rajakannu, G., & Kordestani Ghalenoei, N. (2022). Potential of modular offsite construction for emergency situations: A New Zealand study. *Buildings, 12*(11). https://doi.org/10.3390/buildings12111970

Shahzad, W. M., Reddy, S. M., Kahandawa, R., & Rotimi, J. O. B. (2023). Benefits, constraints and enablers of modular offsite construction (MOSC) in New Zealand high-rise buildings. *Engineering, Construction and Architectural Management*. https://doi.org/10.1108/ECAM-10-2022-1020

Singh, K. (2021). Influencer marketing from a consumer perspective: How attitude, trust, and word of mouth affect buying behavior. *European Integration Studies, 1*(15), 231-241. https://doi.org/10.5755/j01.eis.1.15.28803

Sooriyamudalige, N., Domingo, N., Shahzad, W., & Childerhouse, P. (2020). Barriers and enablers for supply chain integration in prefabricated elements manufacturing in New Zealand. *International Journal of Construction Supply Chain Management, 10*(1), 73-91. https://doi.org/10.14424/ijcscm100120-73-91

Srivastava, M., & Sivaramakrishnan, S. (2021). Mapping the themes and intellectual structure of customer engagement: A bibliometric analysis. *Marketing Intelligence & Planning, 39*(5), 702-727. https://doi.org/10.1108/mip-11-2020-0483

Sutrisna, M., Ramnauth, V., & Zaman, A. (2022). Towards adopting off-site construction in housing sectors as a potential source of competitive advantage for builders. *Architectural Engineering and Design Management, 18*(3), 165-183. https://doi.org/10.1080/17452007.2020.1807306

Taylor, M. D. (2022). A definition and valuation of the UK offsite construction sector: ten years on. *International Journal of Construction Management, 22*(15), 2877-2885. https://doi.org/10.1080/15623599.2020.1829783

Whelan, J., Eeuwijk, J., Bunge, E. M., & Beck, E. (2021). Systematic literature review and quantitative analysis of health problems associated with sexually transmitted neisseria gonorrhoeae infection. *Infectious Diseases and Therapy, 10*(4), 1887-1905. https://doi.org/10.1007/s40121-021-00481-z

Wongwai, N., & Malaikrisanachalee, S. (2011). Augmented heuristic algorithm for multi-skilled resource scheduling. *Automation in Construction, 20*(4), 429-445. https://doi.org/10.1016/j.autcon.2010.11.012

Yang, Z., & Lu, W. (2023, 2023/03/01/). Facility layout design for modular construction manufacturing: A comparison based on simulation and optimization. *Automation in Construction, 147*, 104713. https://doi.org/10.1016/j.autcon.2022.104713

Zahedi, L., & Lu, M. (2022). Optimization of labor flow efficiency in steel fabrication project planning. *Construction Research Congress 2022*, 1261-1269. https://doi.org/10.1061/9780784483961.132

Zyoud, S. e. H., Shakhshir, M., Abushanab, A. S., Koni, A., Shahwan, M., Jairoun, A. A., & Al-Jabi, S. W. (2023). Bibliometric mapping of the landscape and structure of nutrition and depression research: Visualization analysis. *Journal of Health Population and Nutrition, 42*(1). https://doi.org/10.1186/s41043-023-00378-2

Tables:

Table 1. Interview demographics

Interviewee	Construction position	Experience (years)	Construction type	Company size	Number of OSC project
#1	Principle structure engineer	19	Consultancy	Large	1
#2	Project Manager	10	Contractor	Small	5
#3	Senior QS	15	Contractor	Large	1
#4	Site Manager	5	Contractor	Medium	4
#5	Property Development Manager	20	Property development	Large	15
#6	Project Manager	8	Contractor	Small	3
#7	Site Manager	10	Contractor	Medium	8
#8	Site Manager	5	Contractor	Medium	4

Table 2. Summary of key reasons and impacts of labour shortages on OSC adoption

Reasons	**Impacts**	**Supporting references /Interviewees**
	Literature Review	
Difficulty recruiting/retaining skilled labour	Affects project quality and productivity	(Haan et al., 2023; Karimi et al., 2018)
Dependence on less-skilled labour		
Aging workforce	Decreased efficiency, higher costs, extended project timelines, safety concerns	(Oh et al., 2023)

Stricter immigration policies reducing labour availability	Slowed industry growth and difficulty meeting client demands	(Mohamed et al., 2017)
Training gap in advanced manufacturing and technologies (e.g., BIM, robotics)	Skill mismatches, project delays, reliance on inexperienced workers	(Ding et al., 2023)
Lack of skilled engineers	Delayed development of the construction industry	(Hazeen Fathima & Umarani, 2023)
Shortfall in engineering expertise and poor recruitment decisions	Delays in project execution	(Akinshipe et al., 2022)
Reluctance of small employers to invest in recruitment due to high turnover rates	Lower labour productivity and project delays	(Ayodele et al., 2022; Chang-Richards et al., 2017)
Skill shortages in design, logistics, installation	Hindered growth of OSC, lower adoption rates	(Navaratnam et al., 2019; Navaratnam et al., 2022)
Lack of experience and technical standards in structural integrity, fire safety, acoustics, etc.		
Shortage of skilled workers slowing the growth of OSC	Decelerated adoption of Construction 4.0	(Ruoheng et al., 2019; Taylor, 2022)
Persistent skilled labour shortages despite government incentives	Barriers to widespread implementation of OSC	(Alawag et al., 2021)
Shortage of trained professionals	OSC inefficiencies and difficulty in scaling OSC for housing	(Arif et al., 2012; Hashemi & Hadjri, 2014)
	Semi-Structured Interviews	
Aging workforce	Loss of experience and specialised skills in OSC	Interviewees #1, #4, #5, #8 (Saad et al., 2022)

Language barriers and challenges sourcing skilled workers	Misunderstandings, mistakes, reduced workforce efficiency	Interviewee #3
High worker turnover rates	Disrupted project continuity and difficulty maintaining a consistent, experienced workforce	Interviewee #4 (Ayodele et al., 2022)
Absence of training programs for OSC-specific skills	Knowledge gaps, inefficiency in OSC methodologies	Interviewees #1, #4, #7, #8 (Gumusburun Ayalp & Ay, 2021; Kordestani Ghalenoei et al., 2022)
Perception of OSC as a secondary option	Scarcity of multi-skilled labour, higher wages, longer project timelines, inflated costs	Interviewees #2, #5, #6 Ginigaddara et al. (2022)
Visa regulations exacerbating labour scarcity	Delays, increased costs, difficulties in adhering to schedules	Interviewees #2, #3, #6, #7

Table 3. Summary of benefits, challenges, and practices of using multi-skilled resources derived from the literature review

Aspects	**Benefits**		**Challenges**		**Best Practices**	
	Summary	**References**	**Summary**	**References**	**Summary**	**References**
Production efficiency	Enhances production flexibility and resource allocation	(Nasirian, Arashpour, Abbasi, Zavadskas, et al., 2019; Wongwai &	High cost and time investment in cross-training workers	(Nasirian et al., 2022)	Implement Digital Twins to manage labour variability	Barkokebas et al. (2023)

		Malaikrisanachalee, 2011)				
Productivity improvement	Reduces project timelines and increases productivity	(Goh & Goh, 2019; Nasirian, Arashpour, Abbasi, & Akbarnezhad, 2019)	Difficulty in optimal deployment of multi-skilled workers across diverse tasks	(Arashpour et al., 2015)	Apply total quality management and automation	(Goh & Goh, 2019)
Cost reduction	Lowers labour costs by reducing workforce size while maintaining productivity	(Arashpour et al., 2015)	Difficulty in effectively integrating processes and reallocating resources from underutilised to overburdened areas, which can exacerbate costs, inefficiencies, and safety risks in OSC	(Arashpour, Wakefield, et al., 2018)	Optimise skill mixes through cross-training, using performance metrics to design integration frameworks, and managing capacity imbalances and production variability	(Arashpour et al., 2015)
Dynamic task reassignment	Allows for dynamic task reassignment based on	(Barkokebas et al., 2023)			Use integer programming and stochastic modeling to reduce costs and	(Arashpour, Kamat, et al., 2018)

	real-time needs				enhance efficiency in workforce planning	

Table 4. Summary of benefits, challenges, and practices of using multi-skilled resources derived from the semi-structured interviews

Aspects	Benefits		Challenges		Best Practices	
	Summary	**Interviewees/ Supporting references**	**Summary**	**Interviewees/ Supporting references**	**Summary**	**Interviewees/ Supporting references**
Smoother task transitions	Enables smoother transitions between tasks and mitigates delays due to labour shortages	Interviewees #1, #2, #3, #4, #5, #6, #7, #8 (Nasirian et al., 2022; Zahedi & Lu, 2022)	High cost and time needed for certification and training for advanced multi-skilling	Interviewees #1, #2, #3, #4, #6, #7, #8 (Arashpour et al., 2015; Nasirian et al., 2022)	Pinpointing transferable skills enables workers to transition between roles smoothly, boosting flexibility and adaptability	Interviewees #1, #2 (Lin et al., 2020)
Cost reduction and efficiency	Reduces the need for task-specific specialists, lowering costs and improving	Interviewees #1, #2, #3, #4, #5, #6, #7, #8 (Gouda et al., 2017; Nasirian et al., 2022)	Requires identifying individuals capable of excelling in multiple roles, making	Interviewees #1, #2, #3, #4, #5, #6, #7 (Chen et al. (2022); (Zahedi & Lu, 2022)	Strong commitment to training and development is fundamental for multi-skilling	Interviewees #3, #7 (Chen et al., 2022; Perera et al., 2022)

	efficiency		resource management and training programs crucial			
Accelerated project delivery	Speeds up project completion by enabling workers to perform multiple tasks efficiently	Interviewees #1, #2, #3, #4, #5 (Arashpour et al., 2015)	Balancing training costs and higher wages for multi-skilled employees can increase project expenses	Interviewees #1, #6, #8 (Nasirian et al., 2022)	Invest in targeted multi-skilling programmes, adhere to industry standards, and acquire necessary certifications to optimise workforce efficiency and reduce delays	Interviewees #4, #6 (Perera et al., 2022)
Demand-based workforce reallocation	Balances variations in project demand by reallocating workers based on needs	Interviewees #1, #3, #5, #6, #7, #8 (Arashpour et al., 2015)	Multi-skilling's efficiency varies depending on the type of construction or manufacturing involved	Interviewee #5, #6 (Zahedi & Lu, 2022)	Standardising processes and products is essential for operational efficiency and reducing errors	Interviewees #5, #8 (Anastasiades et al., 2021)

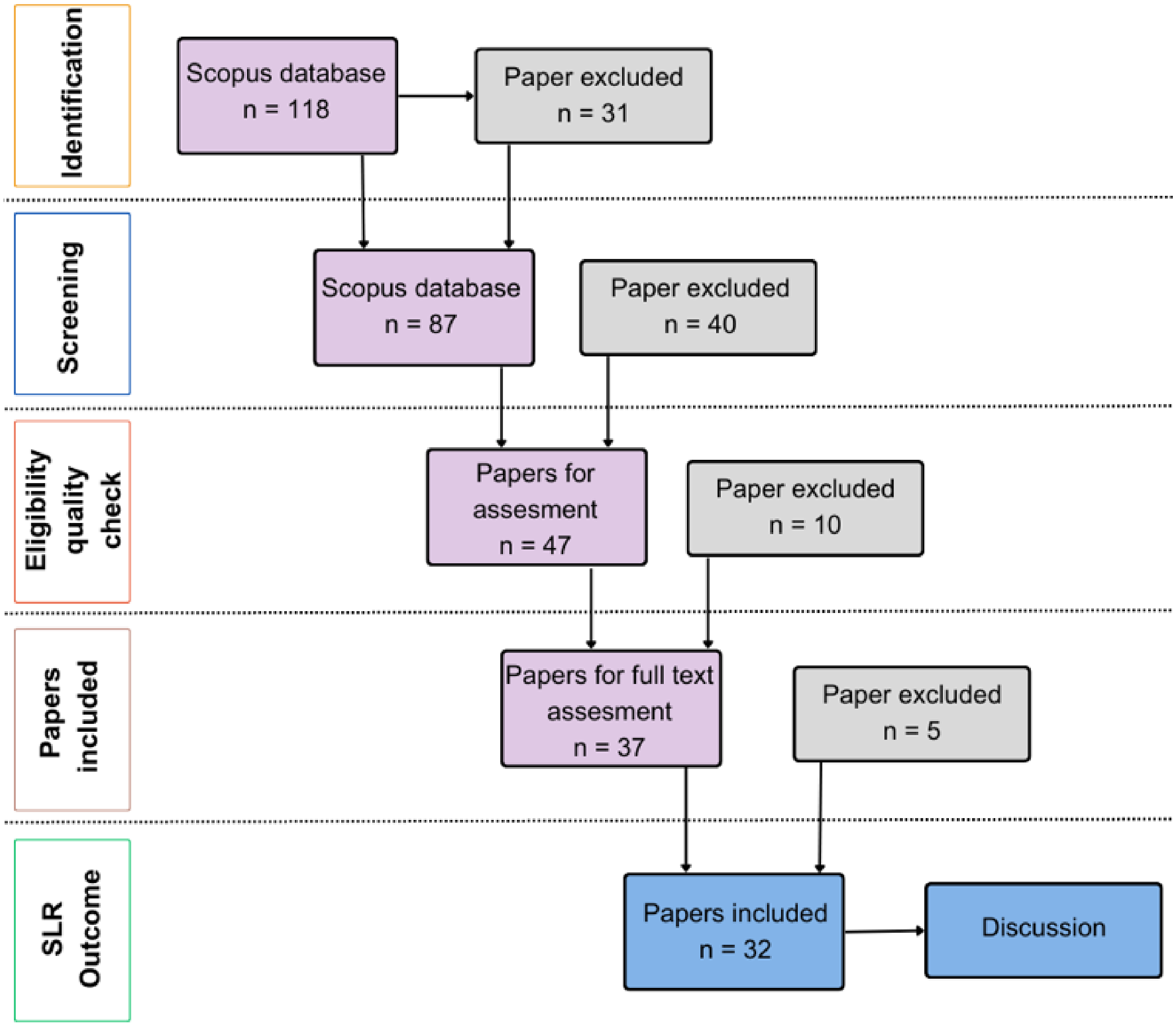
Figure Caption List:

Fig. 1. PRISMA protocol guidelines in the systematic literature review process.

Fig. 2. Labour dynamics in OSC projects.

Fig. 3. Effective implementation of multi-skilling practices in OSC.

Fig. 4. Research results.



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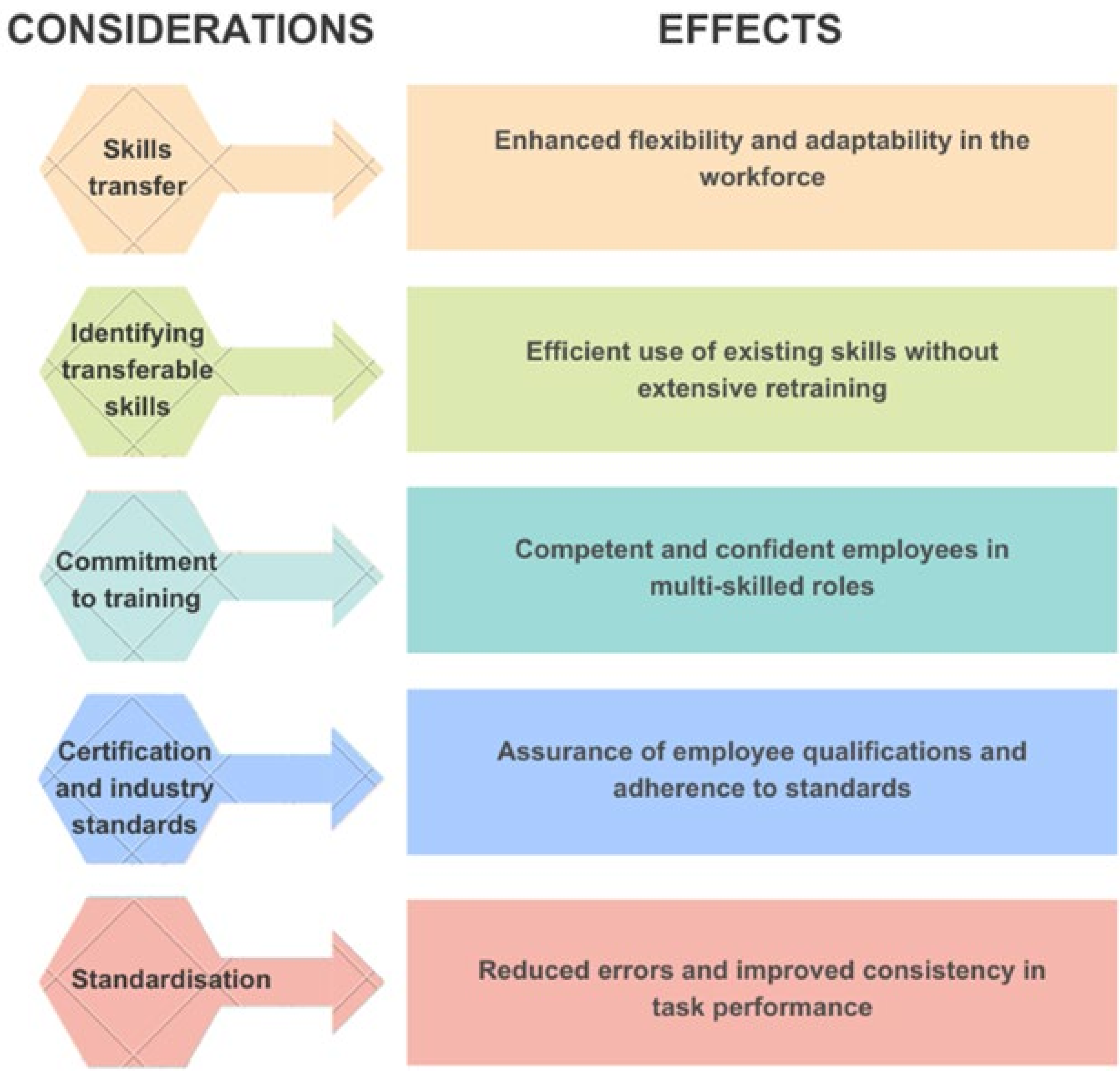

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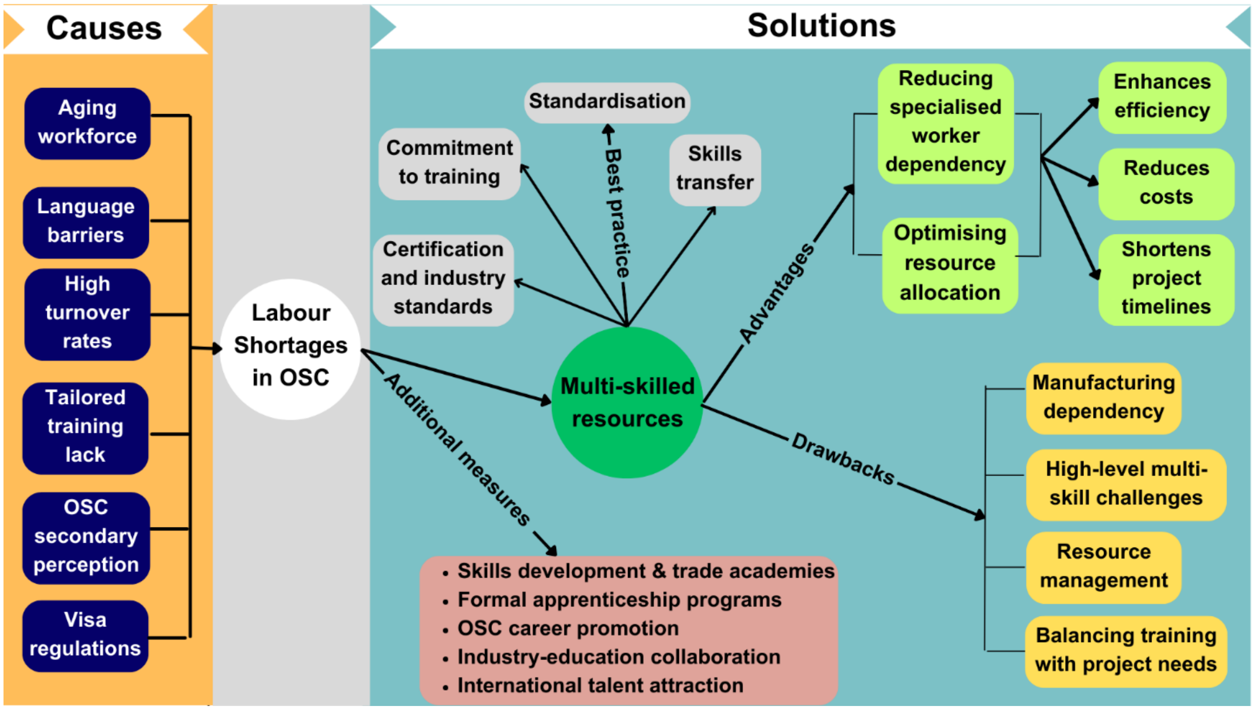

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