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PREVALENT FACTORS AFFECTING WORKERS IN INDUSTRIALIZED CONSTRUCTION: TOWARDS HUMAN-CENTRIC CONSTRUCTION MANUFACTURING

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ABSTRACT: Construction manufacturing has grown in prominence as an effective paradigm for achieving productive, safe, high-quality, and sustainable construction. The manufacturing system has been the focal point of production, adopting advanced technologies to maximize productivity, increase efficiency, and optimize processes. However, the importance of the human element has been marginalized while the workforce remains the backbone of the industry, reflecting a pressing need to shift towards human-centric construction manufacturing. Although there is a positive influence of construction manufacturing on worker safety, ergonomics, work-life balance, fatigue, stress, and overall job satisfaction, the literature lacks a comprehensive inventory of the factors affecting construction manufacturing workers that could be leveraged by managerial staff to inform their decision-making. As such, the present study seeks to identify the factors influencing workers in the construction manufacturing industry as an important step in the shift toward human-centric construction manufacturing by conducting a scoping review of the literature. A total of 95 articles were found to be eligible for inclusion in the review. The analysis reveals a total of 38 prevalent factors categorized as follows in descending order of the frequency of occurrence: physical, vocational, production-related, social, intellectual, indoor environmental quality, and financial factors. Ergonomics, safety, worker-task allocation, training, and multiskilling were found to be among the most frequent factors. Identifying these factors can aid construction manufacturing management in better understanding the needs of workers, conducting baseline analysis, identifying opportunities for improvement, adopting appropriate measures to improve worker well-being, and designing construction manufacturing systems that are human-centric.

1. INTRODUCTION

In construction manufacturing (CM), building elements (e.g., walls, floors, doors, etc.) are fabricated in an off-site production facility and are then shipped to the construction site for installation and assembly. CM has been well-established as a successful paradigm for achieving productive, safe, high-quality, and sustainable construction (Staib *et al.* 2008). Technological adoption, upon the fourth industrial revolution, has been a key enabler of this success thus helping in improving the productivity and efficiency of the industry as well as optimizing processes (Wang et al. 2020). While this technological integration has been the focal point of construction systems, the importance of the human element in the production process has been marginalized (Bidhendi and Poshdar 2024). Given that the workers are the backbone of the industry, it is essential to consider the shift towards the fifth industrial revolution with a focus on human-centric approaches. Human-centricity simply means placing the well-being of the workers at the center of the

production process (Lu *et al.* 2022). Well-being, in turn, can be defined as the way humans feel and how they function in their personal life as well as at their workplace. Well-being covers different dimensions, including physical, emotional, social, environmental, financial, etc. aspects (Jarden *et al.* 2023). Construction organizations are starting to recognize the need for human-centricity by prioritizing the needs of their employees. The transition has been deemed to be beneficial in terms of improving workers' health, safety, and job satisfaction as well as promoting growth and professional and personal development (Bidhendi and Poshdar 2024).

Although human-centric studies in the CM industry are becoming more widespread, these studies typically target a certain aspect of human centricity as opposed to the concept as a whole. When discussing human-centricity in the CM industry, one can consider the focus on assessing workers' well-being and taking the necessary measures in order to promote well-being (Alazzaz and Whyte 2014). For example, ergonomic risk in the MC industry can influence the physical health of workers based on their posture, force required, repetitive activities, and indoor environmental conditions. This can result in pain, injuries, discomfort, and musculoskeletal disorders Assaf, et al. (2024). Researchers have then started looking into studying different workstation designs at the production facility to reduce the ergonomic risk and ensure a healthy working environment (Wang et al. 2023). Another example is related to the skills of the workers in the MC industry. Firstly, studies have looked into identifying the skillset that is required by the workers in the CM industry in order to ensure that they are equipped with the right skills. Being equipped and well-trained on the skill set of interest can help workers smoothly perform their tasks while meeting the required productivity levels (Assaad *et al.* 2022). Studies have also investigated upskilling workers and multi-skilling them in different trades so that, when needed, they can comfortably perform the tasks without the need to learn and perform on the spot (Nasirian et al. 2018). Moreover, Assaf et al. (2024) have analyzed the layout of a precast concrete factory in order to reduce the labor travel time within the factory. Workers can then use the reduced travel time for more meaningful tasks that add value to the worker and to the production process. Additionally, Assaad et al. (2023) highlight the importance of efficient scheduling and planning in improving workers' productivity. Considering the interrelated activities in CM projects, poor planning and coordination can result in schedule delays, leading to the wasting of resources due to idle workers waiting on work.

It is evident that the CM industry is in a transitional phase to achieve human-centric CM in an effort to enhance workers' well-being, along with optimizing the process and improving efficiency. However, these human-centric concepts in CM are spread across different studies and sources, and the literature lacks a comprehensive inventory of the factors that affect CM workers that could be leveraged by managerial staff to inform their decision-making. As such, the objective of this study is to identify and rank the factors influencing workers at the CM production facility through conducting a review of the literature. Once the factors are identified, practitioners and researchers can identify which worker-specific factors are well developed and which require more research and attention in order to support the shift of the CM industry toward human-centric approaches. Additionally, management can investigate how these factors impact workers, obtain a current state assessment, and make the necessary measures. These measures will help foster a supportive, comfortable, healthy, and productive working environment to ultimately achieve a human-centric environment.

2. METHODOLOGY

In order to identify the factors that affect workers in the CM industry, this study adopts a scoping review methodology based on the framework proposed by Arksey and O'Malley (2005). The methodology is composed of 5 main steps: 1) Identifying research questions, 2) Searching for relevant studies, 3) Selecting relevant studies, 4) Extracting data, and 5) Summarizing the data.

In the first step, based on the conducted review of the literature related to the shift of CM industry towards human-centric approaches and the need for identifying the factors that affect workers, the research questions identified are "*What are the factors that affect workers in the CM industry?"* and "*what are the most frequent factors?"* In order to answer these research questions, and as part of the second step, the authors first identified a set of keywords that can potentially be used to identify these studies. The keywords for the search were identified through an iterative process and covered keywords related to CM and keywords related the workers. The list of keywords used is as follows: (*"modular construction" OR "modular*

and integrated construction" OR "construction manufacturing" OR "off-site construction" OR "offsite construction" OR "industrialized construction" OR "prefabricated building" OR "precast construction" OR "pre-cast construction") AND ("worker" OR "labour" OR "labor" OR "operator" OR "workforce" OR "human" OR "crew"). The authors selected the Scopus database to conduct the search as it includes a good coverage of construction-related topics as well as a good range of journal publications (Martinez *et al.* 2019). The Scoups database was searched using the identified set of keywords. The last search was conducted in June 2024 (from the year 2000), whereby a total of 2,314 studies were identified. In order to select the relevant studies, as per step 3, the authors defined certain exclusion criteria as follows: is not in the English language, is not related to the CM industry, does not explicitly target the workers, is not related to building construction, and addresses stages in the CM process that are outside of the factory (e.g., installation phase). After that, the authors followed a two-level screening approach for these studies. The first stage included title and abstract screening, whereby a total of 2,116 studies were excluded, and 198 studies remained. Then, these studies were further screened based on a full-text review as per the identified exclusion criteria whereby 103 of them were excluded, and 95 studies were identified to be eligible for inclusion in this review. Figure 1 represents the PRISMA diagram summarizing the screening process. The eligible studies were further discussed in order to collect the data of interest, including 1) the objectives of the study and 2) the factors that are related to the workers (step 4). The last step was to summarize the extracted data whereby the authors identified the list of factors that impact workers in CM facilities, grouped these factors into categories, studied different trends, and discussed how such insight can be leveraged by the CM management to improve workers' well-being and productivity to achieve human centricity.

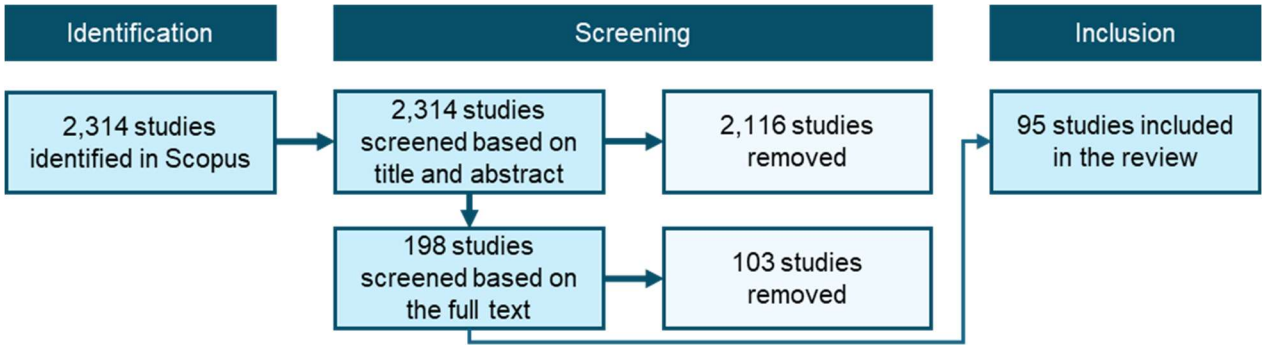

Figure 1PRISMA diagram

3. PREVELANT FACTORS AFFECTING WORKERS IN CM

Based on the review conducted, a total of 38 factors were identified that affect workers in the CM industry. These factors were grouped into 7 categories: 1) physical factors, 2) social factors, 3) indoor environmental quality (IEQ) factors, 4) financial factors, 5) production-related factors, 6) vocational factors, and 7) intellectual factors. Table 1 shows a summary of these factors along with the corresponding category. It should be noted that the factors were extracted from the 95 papers identified in this review. However, due to space limitations, not all of the references were included in the writing of this paper. Moreover, section "4. Discussion" elaborates more on the quantitative analysis of these factors. The following subsections discuss each of the 7 identified categories. It should be noted that a lot of these factors are interrelated and often impact one another. The authors show a suggested selection of factors grouped into different categories. While a certain factor might be relevant to more than one category, the selection of its corresponding category was based on the context it was used for based on the corresponding study.

Table 1: List of factors affecting workers in CM facilities

Category	Factor	Number of studies
Physical Factors	Ergonomics	28
	Safety	25
	Fatigue	10
	Injuries	6

	Physical demand	4
		73
Vocational Factors	Worker-task allocation	12
	Training	11
	Multiskilling	11
	Skillset	8
	Job satisfaction	2
	Absenteeism	2
		46
Production-related Factors	Workload	8
	Quality	7
	Machines/equipment	5
	Congestion/overcrowding	5
	Working hours/working schedules	5
	Resource availability	5
	Layout	3
	Change order	2
		40
Social Factors	Interpersonal relationships	8
	Communication	6
	Coordination	5
	Supervision	5
	Collaboration	3
	Work-life balance	3
	Diversity	3
		33
Intellectual Factors	Awareness	7
	Learning ability	7
	Mental demand	4
	Education level	3
		21
Indoor environmental quality Factors	Noise	3
	Temperature	3
	Air quality	3
	Light	2
	Humidity	2
		13
Financial Factors	Compensation	4
	Incentives/ rewards	4
	Project budget	2
		10

3.1 Physical factors

Physical factors cover the bodily functions of the workers that directly affect their health, safety, and performance. Addressing these factors effectively can lead to a reduction in workplace injuries, enhanced compliance with safety standards, and improved job satisfaction (Wang *et al.* 2022). Some of the physical factors identified in this review include ergonomics, safety, fatigue, injuries, and physical demand. Zhang and Lin (2023) introduced a simulation-based approach to quantitatively predict ergonomic risks and evaluate their impact on construction schedules. The study considers workers' ergonomic risks, fatigue, physical capacity, and age as critical factors in the proposed model and demonstrates how mitigating them can improve health and productivity and optimize schedules. Similarly, Wang et al. (2023) provided an

automated ergonomic risk analysis to evaluate workplace designs in a modular construction facility. By employing tools such as Rapid Entire Body Assessment (REBA) and Rapid Upper Limb Assessment (RULA), the study proposes a method to obtain standard motion times for hypothetical manual operations and evaluate the ergonomic risk of continuous motions. Additionally, it identifies the optimum workstation design in a less time-consuming and cost-effective way. By doing so, the study underscores the importance of proactive ergonomic strategies to enhance safety and performance. Expanding on safety-related factors, (Vithanage *et al.* 2022) developed a Bayesian Network system to evaluate the interrelationships among different safety-influencing factors and their collective impact on safety performance in construction manufacturing. The study identifies training quality, co-workers' safety practices, and management's safety response as the most influential factors affecting safety performance and worker behaviour. These findings highlight key areas for companies to enhance workplace safety and foster a safer, more efficient working environment. On the other hand, manual and repetitive tasks remain inevitable in construction, often leading to musculoskeletal injuries and disorders. To address this, Li et al. (2017) proposed a framework to investigate muscle fatigue caused by repetitive lifting tasks in construction manufacturing operations using surface electromyography (sEMG) and human body modeling. The results showed that while sEMG effectively analyzed superficial muscle activity, its limitations in detecting deep muscle fatigue were addressed by the human body model, which successfully predicted variations in muscle forces throughout the lifting cycle. This approach enabled the identification of ergonomic risks and supported workspace redesign to enhance workers' safety and efficiency.

3.2 Vocational factors

Vocational factors are related to the skills, interests, and work-related values that impact workers' career choices and professional development. Some factors under this category include training, task allocation, multiskilling, skills identification and development, job satisfaction, etc. Assaad et al. (2022), examined how construction manufacturing influences workforce skills and job demand. The study explored whether construction workers need to develop new skills or enhance existing ones, how technical and managerial competencies evolve across roles, and which skills should be prioritized in training programs. The findings emphasized the need for upskilling across all off-site workforce occupations, highlighting the importance of implementing dedicated training initiatives. This is particularly crucial since some off-site skills differ from those required in on-site construction. Similarly, Rotimi et al. (2022) identified essential skills in New Zealand's prefabricated residential construction sector, stressing the necessity of improving vocational skills. Moreover, Nasirian et al. (2018) created a mathematical framework to explore how incorporating a multiskilled workforce can enhance tangible performance measures such as reducing costs and production time. The results revealed that employing a cross-trained workforce led to a 41% improvement in the duration and a 17% reduction in labour costs. A critical factor highlighted in this study is worker-task allocation, which ensures that workers with diverse skills are assigned tasks that align with their abilities, which leads to better task completion, reduced downtime, and a more flexible workforce.

3.3 Production-related factors

Production-related factors cover variables and conditions associated with the methods, processes, tools, and systems used in construction production. Under this category, key factors affecting workers in construction manufacturing have been identified. Some of them include workload, production quality, machine operations and maintenance, congestion, working schedule, etc. For instance, Chandler and Sunindijo 2024) identified workload, long hours, work pressure, and job control as critical factors in prefabrication systems. The study found that prefabrication helps alleviate workload challenges by reducing long hours and work pressure. Moreover, having more job control benefits workers by reducing stress and increasing satisfaction. For example, the ability to adjust their working schedules helps balance personal responsibilities, and the flexibility allows workers to perform at their best. Moreover, van Dijkhuizen et al. (2021) developed a conceptual model to determine the impact of off-site construction on labor productivity. The study highlights influencing factors such as change orders, schedule changes, overcrowding, rework, schedule pressure, and waiting time. For example, off-site construction faces challenges with late customer changes and changing orders, which can halt production and cause waiting time, negatively impacting workers' well-being (van Dijkhuizen *et al.* 2021). On the positive side, off-site construction helps improve worker well-being by reducing overcrowding, minimizing rework, and allowing for better planning, which

lowers schedule pressure and supports a healthier environment for the workers. In another study, Alsakka et al. (2023) introduced a qualitative method to identify the factors affecting cycle times at the workstation level in off-site construction facilities. Some of these factors directly impact workers' well-being, such as work shifts, the day of the week, and machine breakdowns. Work shifts (e.g., morning, afternoon) impact workers' fatigue, with younger workers experiencing mental exhaustion later in the day during their afternoon shifts. Productivity and energy levels also change throughout the week as Mondays can be slower due to the weekend recovery. Additionally, machine breakdowns create stress, with minor issues causing frustration to the workers and major failures disrupting the workflow. These factors align with the Lean construction principles, which aim to design processes at the CM facility to minimize waste in various forms and maximize value. Reducing process waste can help optimize the workers' efficiency by empowering them and seeking continuous improvements (Mostafa *et al.* 2016).

3.4 Social factors

Social factors cover the interactions, relationships, and support among workers and managers that influence teamwork, communication, and overall well-being. These factors include interpersonal relationships, collaboration, communication, supervision, work-life balance, etc. According to (Chandler and Sunindijo 2024) work and family are essential parts of life and balancing them is important for stability. However, in the construction industry, long hours and demanding projects often interfere with workers' personal lives, leading to stress and lower job satisfaction. On the contrary, prefabrication has shown a positive impact on job satisfaction partially coming from an enhanced work-life balance. Furthermore, Alazzaz and Whyte (2015) explored the link between productivity and employee empowerment to better understand efficiency in off-site sub-element fabrication. Their study highlighted leadership, teamwork, and communication as key empowerment factors that contribute to a positive work environment and overall company success. Moreover, Chunguang and (Teng 2020) used Grounded Theory (GT) to identify risk factors and develop a conceptual model, while the Structural Equation Model (SEM) was applied to determine how these factors affect construction safety. The results showed that management risks had the greatest impact, particularly in areas related to team coordination and communication, as poor coordination can lead to errors, delays, and safety hazards, affecting workers' well-being.

3.5 Intellectual factors

Intellectual factors cover the mental abilities and cognitive processes that influence workers' capacity to think, learn, understand, and make decisions. Some of the aspects of this category include awareness, mental demand, learning ability, and education level. Regarding the intentional unsafe behaviours of precast construction workers, Yao et al. (2024) constructed a theoretical model using structural equation modeling to highlight key cognitive and behavioral factors influencing intentional unsafe behaviours among workers. Perceptual behaviour control, attitudes, risk preference, and subjective norms significantly impact workers' intentions to engage in dangerous practices. However, personal risk preference, which refers to a worker's tendency to either avoid or accept risk when making safety-related decisions, contributes to 7.71% of intentional unsafe behaviour. Additionally, behavioural beliefs and comfort play a crucial role because workers tend to underestimate risks or practice unsafe behaviours when they perceive them as convenient or unlikely to cause harm. The study suggests strengthening safety awareness through training, real-life accident case studies, and immersive tools like virtual reality. These approaches highlight the importance of developing safety frameworks and fostering a strong safety culture, which is essential for improving worker well-being and reducing accidents. Similarly, Wang et al. (2020) identified and organized the key factors influencing unsafe behaviours among prefabricated construction workers and proposed mitigation measures. In their study, the factors are divided into three main categories: attitudes, subjective norms, and perceived behavioural control. Within attitudes, risk perception and the desirability of safe versus unsafe behaviours are key; if safe behaviours are seen as inconvenient, workers may choose unsafe ones. In subjective norms, managerial and worker pressure affect decisions, either through rewards, penalties, or the desire for social approval among colleagues. Finally, perceived behavioural control includes workers' judgment of their knowledge and capabilities, which determines whether they feel capable of performing safe behaviours or resorting to unsafe ones due to external constraints. Therefore, increasing supervision is one of the suggestions to approach safe behaviours and increase the safety of each construction worker.

3.6 Indoor environmental quality factors

Indoor environmental quality (IEQ) refers to the environmental conditions within a CM production facility that impact occupants' well-being. Ensuring high IEQ in OSC is essential for a comfortable and productive workplace since it affects workers' performance (Mahbob *et al.* 2011). Key factors of IEQ include temperature, thermal comfort, noise exposure, lighting conditions, etc. (Bluyssen 2009). Dabirian et al. (2018) developed a framework to assess workers' noise exposure levels in a CM facility. Since CM workers are often exposed to different noise sources (cutting, nailing, material handling, etc.), this can lead to adverse psychological effects. This study highlights the importance of mitigating the impact of high noise levels and improving operational planning. In a follow-up study, Dabirian et al. (2020) proposed a framework to assess workers' noise exposure levels to develop noise maps that reveal safe zones and high-risk areas, emphasizing the need for targeted noise mitigation strategies. Furthermore, Cui et al. (2022) presented a framework to simulate occupational health risks faced by workers in precast concrete plants. The study provided various environmental factors that impact the health and safety of the workers, including exposure to carbon dioxide, dust, formaldehyde, noise, volatile organic compounds, high temperatures, and humidity. The study then proposed a lifecycle risk management framework to analyze the emission sources and the mitigation mechanisms and developed a simulation model for occupational health risk assessment. With regards to workers' thermal comfort, (Alsakka *et al.* 2023) interviewed workers in a CM facility and revealed that workers were getting tired more quickly and undertaking their tasks slower during high temperature days in Summer.

3.7 Financial factors

Financial factors are not limited to objective measures like income or savings, but also include subjective perceptions, such as confidence in one's financial knowledge, ability to achieve goals, and overall financial security (Brüggen *et al.* 2017). In this review, these factors operate on two levels: industry-related factors, such as wages, benefits, and incentives provided by employers, and personal factors, including financial stress and socioeconomic status (Fagbenro *et al.* 2024). These elements collectively influence how individuals navigate financial challenges, make decisions, and maintain both short-term stability and long-term resilience, highlighting their pivotal role in well-being and productivity. (Chandler and Sunindijo 2024) determined the effects of prefabrication on job satisfaction and working conditions among construction workers in Australia. Their study emphasizes that compensation, including wages and benefits provided by employers, significantly influences workers' job satisfaction. Consequently, higher levels of satisfaction contribute to better work conditions and ultimately enhance project outcomes. Similarly, (Fagbenro *et al.* 2023) explored the role of prefabrication in addressing mental health challenges within the construction industry. Through a comprehensive literature review, the study identified financial difficulties and low socio-economic status as some of the stressors affecting workers' mental health. Moreover, this study affirms that prefabrication can help mitigate these problems by ensuring job security and providing opportunities for upskilling and career development. As a result, it reduces financial pressures and improves workers' socio-economic conditions. By addressing and improving workers' financial stability, companies can foster job satisfaction, enhance individual performance, and drive organizational success.

4. DISCUSSION

The chart in Figure 2 represents the frequency of each of the 38 factors influencing workers in the CM facilities, along with that of the categories. The factor frequency refers to the number of the studies that targeted the factor of interest, while the category frequency refers to the sum of the corresponding factors' frequencies, reflecting the number of times the factors of this category appeared in the studies. It is worth noting that a single study can address more than one factor in the same category or in different ones.

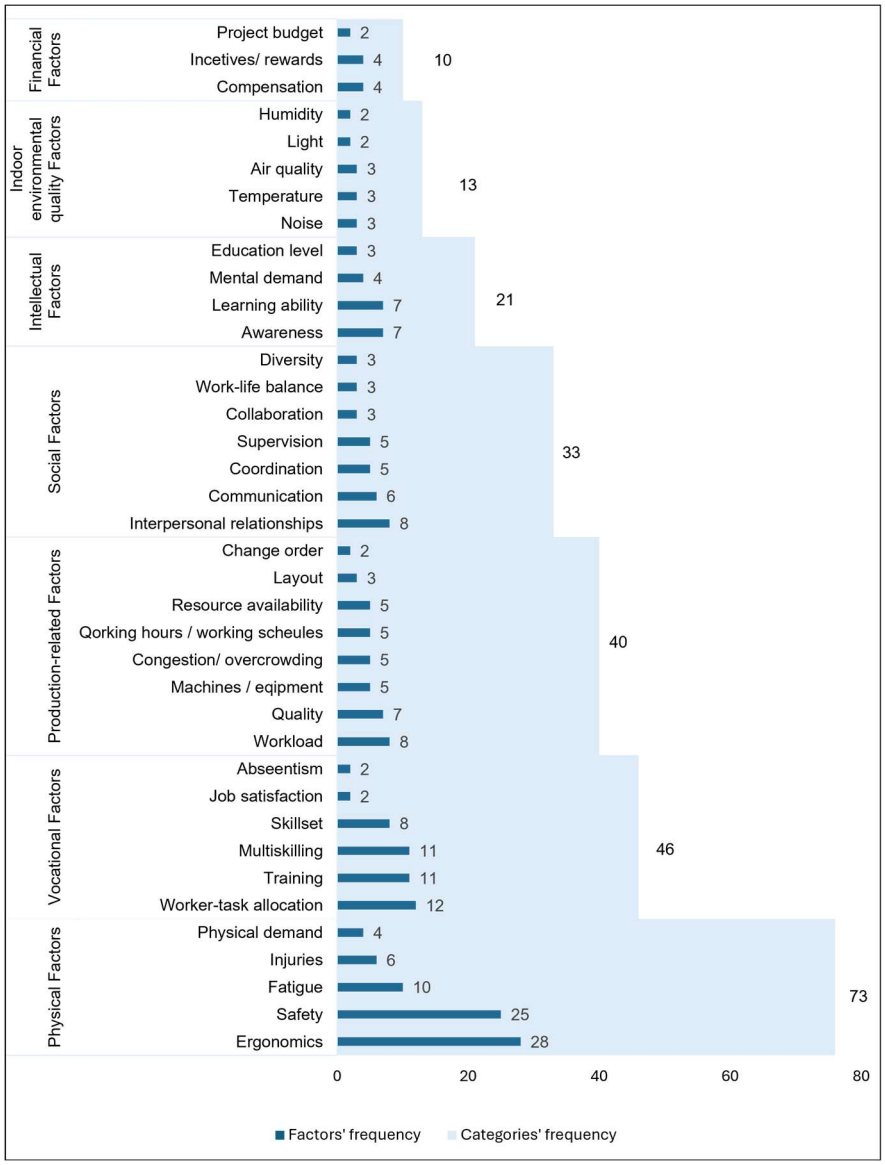

Figure 2: Ranking of prevalent factors influencing workers in CM

The physical factors category showed the highest frequency of 76 (i.e., physical factors appeared 76 times in the selected set of articles) followed by vocational (46), production-related (40), social (33), intellectual (21), IEQ (13) and financial factors (10). This reflects the focus of researchers when it comes to topics related to the workforce in CM. While the workers' physical health, their vocation, and the production process are core elements of the human-centric production approach, there are certain categories that have been given less attention. There is a need to go beyond the tangible aspects of CM to achieve human centricity. As such, researchers are encouraged to further integrate less tangible aspects in managing the factory environment, such as social, intellectual, IEQ, and financial factors. It is evident from the studies extracted that these less frequent categories have a direct impact on the workers and the production accordingly and thus require more attention to amplify their positive impact and mitigate the negative impact. This analysis is also reflected when analyzing the specific factors. The most frequent factor is the ergonomics factor, with 28 of the studies addressing it, followed by safety (25), worker-task allocation (12), training (11), multiskilling (11), etc. On the other hand, incentives/rewards, noise, air quality, educational level, diversity, job satisfaction, etc., were found to be among the least frequent factors. The output obtained and the analysis conducted on the factors affecting workers in CM facilities provide us with an overview of which factors have been well studied and addressed in the literature (e.g., ergonomics, safety) and which

factors are understudied (e.g., diversity and absenteeism). This allows us to identify opportunities for improvement that can help us give more attention to the workers to achieve human centricity. The frequency-based analysis acts as the stepping stone into obtaining a current-state assessment of human-centric research in CM and stresses the need to have a comprehensive integration of these factors when designing human-centric production facilities.

5. CONCLUSIONS

This study presented a scoping review of the CM research to identify the factors affecting workers in the CM facilities as an enabling step to achieve human-centric CM. A total of 38 factors were identified across 7 categories: physical, vocational, production-related, social, intellectual, indoor environmental quality, and financial factors. The categories and the factors were also ranked based on the frequency of occurrence in the eligible studies. Physical factors were found to be the most common, followed by vocation and production-related factors along with the others. More specifically, ergonomics, safety, worker-task allocation, training, and multiskilling were found to be among the most frequent factors. The contribution of this study lies in providing a comprehensive inventory of the factors that affect the well-being of the workers in CM facilities. Identifying and ranking these factors based on their frequency of occurrence reflects which factors have been well-studied and established and which require more research and attention. The ultimate contribution is to help CM management and researchers understand what factors affect workers, which are well established (e.g., ergonomics) and which require more work (e.g., mental demand) to make informed decisions to improve workers' health, comfort, productivity, and well-being. This can eventually help the construction industry achieve human-centric CM. Future works aim to validate the identified factors and the categories with practitioners in the industry and identify specific measures and processes that allow CM factories to leverage these factors in adopting human-centric manufacturing. Moreover, future works of this study aim to consider the duration and the severity of the impact of these factors on the workers since certain factors that are less frequent might have a high and long-term impact on the workers.

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