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Ergonomic Risk Assessment of Aluminum Form Workers' Musculoskeletal Disorder at Construction Workstations Using Simulation

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Abstract: This study analyzes an existing scenario of musculoskeletal disorder (MSD) associated with the ergonomic hazard of the aluminum formwork workstation and its workers. Aluminum form-workers have increasing evidence of MSDs from repetitive tasks such as the adjustment, alignment of pins, pulling, pushing, and installation of panels, because of the cumulative exposure to ergonomic risks. Existing research indicates that this is due to insufficient expertise, form-worker awareness, and a complex construction plan. Using the Tecnomatix process simulate, this study aims to identify awkward postures during the process of lifting, assembling, and installing formwork to quantify MSDs and assess the ergonomic risk of aluminum form-workers and provide simple solutions. This simulation method makes use of input data from a random sample of 92 participants retrieved from four construction sites. The Rapid Upper Limb Assessment (RULA), Ovako Working Analysis System (OWAS) scores, and Energy Expenditure Rate (EER) for three identified awkward cases were determined to be unsatisfactory, unsafe, and acceptable with suggested alternatives. The ergonomic scores correspond to various bodily stresses, allowing workers to better understand which body parts experience major stress when performing manual jobs. The suggested integrated preventive ergonomics system reduces MSDs and improves how people interact with their surroundings.

Keywords: ergonomic risk; aluminum form-workers; musculoskeletal disorder; workstation; Tecnomatix process simulate

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1. Introduction

Despite the advent of construction technology and the ever-increasing dependence on automated technology, a growing number of aluminum (Al)-type form-workers are deployed for repetitive tasks. The Al-type formwork system includes leveling, making a ground sketch, brushing formwork oil, binding a steel bar, pre-embedding a lined tube and line box, setting a steel bar for limiting the width of a concrete wall, assembling panels, installing tie rods and aligners, fastening the nuts, adjusting the verticality of wall panels, and verifying and fixing panels. However, this study focused on form-worker tasks such as panel lifting, assembling, and installation over time. It includes a formwork panel that passes through the lifting box, pulls the formwork panel from the vault in a multistory building, and installs and adjusts the beam panel. Form-workers are a prevalent work-related group of people who spend a lot of time in enforced postures that cause muscle fatigue and musculoskeletal disorders at work. Therefore, MSDs are a prime cause of productivity loss, functional damages, and permanent disability in form-workers [1]. According to previous studies, musculoskeletal injuries and disorders occur gradually when worker activities are frequently repeated with insufficient time for the body parts to recuperate. The research investigated accidents at Korean construction sites and determined the risk of occupational accidents in 26,570 of the 96,656 that occurred in 2016, according to the Korea Occupational Safety and Health Administration. This figure, 29.3%, was the highest as there was an increase of 5.7% with respect to that of the previous year [2]. According to statistics (2021), the prevalence of musculoskeletal disease in the construction industry increased by 28.95 percent between 2010 and 2020 [3]. Overloaded motions and repetitive tasks were the leading causes of MSD [3]. Working with poorly-constructed equipment and in uncomfortable positions caused additional pain, hearing loss, and neuromuscular illnesses in many construction workers [4]. Although fully automated technology is the greatest way to reduce fatigue and injury, ergonomic intervention is necessary and beneficial in the face of major workplace hazards and safety concerns.

Several studies have recommended addressing and correcting MSD problems using wearable sensors, digital human modeling (DHM), and other ergonomic algorithms that enable the real-time assessment of ergonomic risks. Construction sites are generally more dangerous than manufacturing workplaces due to heavy equipment placement, physically and mentally demanding tools, hazardous products, and constantly-fluctuating working circumstances. As a result, the prevalence of workplace accidents, injuries, and deaths involving construction workers is high [5]. Preventive measures have been taken, such as the Ovako Working Posture Analyzing System (OWAS) that is used separately and in combination with other methods for the detection of MSD risks [6], the Rapid Upper Limbs Assessment (RULA) that is most frequently used with other applications for better human health [7], and the Rapid Entire Body Assessment (REBA), which is a biomechanical method of identifying MSD risks. These approaches each have their own limits and explanations. The creation of automated systems for assessing ergonomic hazards has received a lot of attention in recent wearable sensor research, and real-world behaviors in the video are now recognized as assessments of the ergonomic risks associated with linked musculoskeletal automation [8]. During the lifting job, the subject load, angle, and position have substantial effects [9]. Despite these attempts, no workplace device exists that provides employees with real-time information on the risks associated with their posture and gestures. Several studies on the musculoskeletal diseases and stresses experienced by construction workers are available; however, no ergonomic assessment has been conducted to explain and quantify the MSD experienced by construction form-workers. This study aims to fill the gaps in existing aluminum form-workers' MSD problems during the lifting, pulling, and installing process and provide simple, convenient solutions at the workplace.

To assess ergonomics in the literature, most researchers employ questionnaires, simulations, and DHM. However, we found no studies on the postures of form-workers or the assessment of form-workers' occupational injuries. Currently, there is a paucity of studies on construction professions such as welding, ironworkers, and brick workers, in the construction field. As a result, more research is required to address the inadequacies of previous construction studies and to quantify the risk of MSD among form-workers. Herein, the study of modeling samples is divided into three, depending on the task and the repetitive work posture. Case 1: Lift the aluminum panel near the lifting box. Case 2: Pull the aluminum plate using the lifting box. Case 3: Install and adjust the formwork panel. The study can automatically assess workers' ergonomic risks in real-time in any task, highlighting the need for a common framework. This study provides simple strategies to reduce the prevalence of MSDs by simulating awkward form-workers' postures, estimating total ergonomic scores per frame with time. To conduct an ergonomic simulation, the existing layout modeling was created using Computer-aided design (CAD) and then imported to the Tecnomatix human simulation software program. The formwork layout was changed to explain and explore the MSD of a form-worker. Differences in productivity, duration, and worker tiredness are demonstrated by the existence and intervention of construction layout. The major objectives of this study are as follows:

1. To address the awkward postures of aluminum-type formwork tasks based on real site layout and their corresponding durations.
2. To carry out an ergonomic simulation to estimate OWAS, RULA, and EER risk scores for the whole body to provide comprehensive feedback that will enable form-workers to avoid awkward postures.
3. To propose and simulate simple ergonomic solutions to reduce MSD.

In this study, we will identify problems and estimate formwork stresses, which will allow for the prediction and management of construction work safety hazards and, thus, the enhancement of project performances.

2. Related Work

Contribution of Ergonomics and DHM on Industrial Workstations

Ergonomic workstation evaluation is required to ensure correct working postures and workstation configurations. The purpose of ergonomics is to make the workplace as productive, safe, and comfortable as it is practicable. Ergonomic techniques have helped prevent deaths and facilitate safe and healthy practices for construction workers; however, they still seem to have a great potential for a wider application. A complete overview of the uses and developments of DHM systems in the industrial sector has previously been presented [10]. Various forms of computerized human models are used for ergonomic assessments and workplace designs in a variety of fields. Among the applications affected by the manufacturing industry, several categories of professionals such as painters, machinists, polishers, presses, technicians, forklift operators, and warehouse deliverers have been studied [11]. Many existing studies have identified the types of construction injuries that correspond to various construction occupations. DHM is an effective technique for analyzing injuries and predicting ergonomic designs. Since the 1990s, there has been a tendency toward the integration of bidirectional into complex systems and specialized CAD software programs such as Apolinex [11], a human program developed using CAD that manipulates postures for the purpose of ergonomic simulation [12]. These abovementioned software programs differ with respect to their modeling features and parameters. Despite significant development in human body simulation, there are still difficulties to be addressed. The static strength prediction program (3DSSPP) forecasts the dynamic strength of the user for different tasks such as lifts and pushes; however, it should not be utilized as the sole determinant [13]. The most famous modern applications of DHM are as follows: JACK, which is now part of the Tecnomatix software design workspace for optimal human performance [14], and RAMSIS, which is a German acronym computer-oriented anthropometric 3-D mathematics system for vehicle occupant simulation [15]. Through questionnaire-based surveys on different construction occupations, it was found that the rates of work exhaustion and physical sensation symptoms are high among scaffolders, metal-fixers, form-workers, and those working in elevated places [1]. Digital Human Modelling (DHM) software programs such as the Digital Enterprise Lean Manufacturing Interactive Application (DELMIA) were used for different conditions and postures that help to minimize the health risk and problems encountered during the real system; however, they have certain limitations [16]. K2 RULA, a semi-automatic evaluation software program that uses the Kinect sensor, was presented to analyze the different ergonomic postures and compared the JACK toolkit [17]. According to the REBA results, 7.63% of workers are at risk and require an immediate change and 44.6% of them are at high risk and require an immediate change. Previous research has shown that ergonomics in the workplace should effect changes in the workplace design and work organization to meet workers' needs and aim to reduce workplace injuries [18]. The implementation of the DHM software, together with its challenges and practical commendations, was discussed [19]. The adaptation of methods such as biomechanical analysis, motion generation, virtual visualization, sensing, and action recognition from video recordings were done using a case study for ergonomic analysis [18]. In addition, the Siemens NX software program has a DHM module called Tecnomatix that simulates humans to simulate ergonomic postures [20]. The ergonomic analysis on 2D and 3D digital workstations was performed on a different task using Catio, and DELMIA simulation and compared with a traditional approach [21]. The welder's existing postures and adjustment strategy were analyzed using 3D simulation to prevent fatigue and injury [22]. Previous studies have shown that 78% of MSD pains in workers were found during brick and block masonry work [23].

Based on the abovementioned studies, we can conclude that there is a considerable number of studies on ergonomics and DHM in industrial workers such as bricklayers and welders and the workstation scenario which is summarized as Table 1; however, we found no ergonomic studies on construction form-workers' postures. Therefore, to increase the number of studies on the construction field and to identify ergonomic measures of effectiveness, such research, which comes with recommended practical solutions, must continue. Hence, although the present study is a continuation, it is related to the form-workers' MSD investigations using the DHM method known as the Tecnomatix Process Simulate.

Table 1. Applications of ergonomics and DHM on construction industry.

Authors	Few Selected Applications of Ergonomics and DHM on Construction Industry	Outcomes
Chaffin, et al., 1997	3DSSPP and CAD software for biomechanical analysis	Forecasted the user's dynamic strength, but it cannot be used as the sole determinant.
Groblelny, et al., 2008	DHM studies on painters, polishers, technicians and warehouse deliverables	Construction injuries were identified, and ergonomic design for the given profession was predicted.
Constantinescu, et al., 2016, Bubb, 2002	Jack + RAMSIS, optimization for exoskeletons based experiments	Collisions within the exoskeleton were detected, and the workstation was determined to be unsuitable.
Polasek et al., 2015	DELMIA ergonomics software for whole body analysis	Analyzed whole body specific posture but correct manipulation of a posture is a challenging task.
Manghisi, et al., 2016	K2 RULA, a semi- automatic s/w that uses Kinect sensor	Ergonomic posture was examined and compared to the Jack toolkit.
Raschke, et al., 2019	Tecnomatix process simulate software, which is a part of Jack software.	Human postures simulated for ergonomics.
Zhang, et al., 2019	DHM studies on welders' postures and adjustment strategy using Jack s/w + 3D simulation	Workers' fatigue and injury were prevented.
Anton, et al., 2020	Ergonomic research on brick and masonry work	MSD pain was found in 78 percent of construction workers.

3. Materials and Methods

3.1. Software-JACK (Process Simulate Human)

The JACK software program, which is based on Siemens, is a human simulation tool that improves and refines the ergonomic product design and helps to personalize industrial tasks. This software program facilitates manual task planning, which integrates the virtual environment into the simulation. It entails optimizing the arrangement of work areas, as well as assessing the viability of hand assembly. Tecnomatix is an application that provides human-centric modeling software programs for doing ergonomic evaluations on virtual products and work situations. The biomechanical qualities of the Jack humanoid avatar include a realistic range of motion and joints [24]. This software program enables comparisons between worker populations and the testing of designs for many factors, including the risk of injury, ease of operation approachability, line of sight, stress limits, and other human parameters.

3.2. OWAS, RULA, and Energy Expenditure Analysis (EEA)

The worker posture assessment supported by the OWAS identifies three categories: four postures, three on the arms, seven on the legs, five on the head, and the amount of load used [5]. This technique divides the degree of effect into five categories. According to this method, OWAS is categorized into four categories: Category 1: Normal postures that do not require special attention, and Category 2: Postures that have negative consequences and requires immediate correction. Category 3: Postures with detrimental effects on the musculoskeletal system and preventive measures are required as soon as possible. Category 4: Postures that should be reviewed promptly.

RULA is a rapid survey method for use in ergonomic workplace surveys. It is a screening technique for determining a body's biomechanical and psychological strain. It focuses on the neck, torso, and upper extremities. RULA score indicates the degree of action needed to reduce the risk of MSD (1). A minimum RULA score of 1–2 means the pose is acceptable if it is not maintained. (2) A RULA score of 3–4 means that further investigation is needed and requires amendment. (3) A RULA score of 5–6 indicates that the person is working in a bad posture and that additional research is urgently required. (4) A score of 7–8 suggests that more investigations and changes are needed [24,25]. The RULA score represents the risk level of MSDs for the assessed task.

Metabolic Energy expenditure tools predict the metabolic energy expenditure requirements of a job cycle composed of multiple tasks. It bases its prediction on worker characteristics and the type of job that comprise the job cycle to be analyzed. The energy demands for each task are added together with the energy cost of maintaining postures to arrive at the total energy expenditure required for a cycle. This program calculates the number of kcal consumed in each simulated action, including posture and force needs. The energy expenditure ratio (kcal/min) calculated from the energy cost estimations is compared to the fatigue acceptable limit to determine exhaustion. The metabolic energy expenditure rate is the product of the basal metabolic rate and physical activity level [26].

3.3. Flow Chart of the Research Methodology

The aluminum formwork procedure, which includes erection, installation, curation, and disassembling, was reviewed and analyzed to capture its different repetitive working awkward postures. Figure 1 depicts the research methodology in eight steps. Step 1 identifies the problems based on aluminum form-workers throughout the formwork installation process. Step 2 explains the study regarding the existing form-workers' issues around the construction site and photographs were taken; Step 3 depicts the workers' awkward postures from the construction site. Step 4 describes the aluminum formwork layout and transfers it to run the Tecnomatix process simulate software. The simulation runs creating a virtual environment of a formwork construction site with workers' different postures and conducting ergonomic assessment in step 5. RULA, OWAS, and EER are part of the Tecnomatix simulation. JACK (Ergonomic assessment) is incorporated into the process simulate model and executed from a simple reach and clearance investigation, injury risk, strength, strain, and task-scheduling assessment. Step 6 will check for posture acceptance, and if the outcome (posture) is acceptable, the worker will move on to the next task, which is step 7. Otherwise, as shown in step 8, the working layout will change and be simulated again. The task simulation builder system (TSB) in Jack (Tecnomatix process simulate) has the following main characteristics. It is a natural instruction interface. Terms like get, put, position, go, apply, and force are utilized within the TSB. The activities are defined in a natural instruction and what is to be done in a natural way. For the entities in the simulation, this automatically depends on empirical motion models. If numerous actors are engaged, it is concerned with the task execution order and has accumulated all analysis and animation results such as walking, standing, sitting, bending, and reaching, and so on. It depicts the human response over a period of time. The ergonomic report for the job sequence is created using a simulation, which includes injury risk, motion repetition, task time, and RULA.

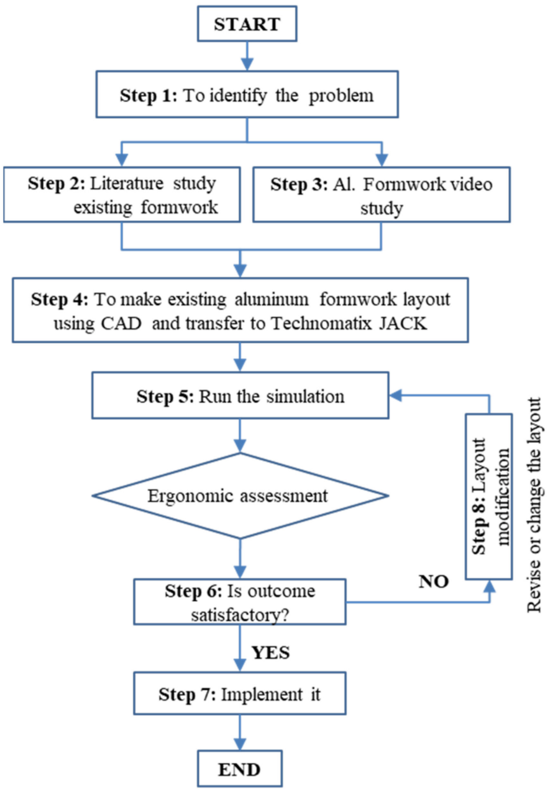

Figure 1. Research methodology.

Figure 2 shows the detailed procedure of the test-study ergonomic analysis of aluminum form-workers. The simulation prototype study was categorized into three cases as follows: Case 1: Lift the aluminum panel near the lifting box, Case 2: Pull the aluminum panel (AP) from the lifting box, Case 3: Install and adjust the formwork panel. These three test cases were studied because they are repeated and lasting risk events. Ergonomic simulations begin with the creation of a 3-D in CAD and its importation into the Tecnomatix process simulate program. For manual operation animation works, a digital humanoid was created. The manikin was positioned using the GET, PUT, and WALK commands. The duration of the posture practice, as well as the time and load, were adjusted. The simulation was conducted, and ergonomic reports on human performance on a particular activity were obtained. The three-dimensional model was established for ergonomic simulation to identify the OWAS, RULA, and EER scores based on the worker's repetitive awkward posture. The suggestion is provided based on the simulation result of Case-2 to reduce the MSD. Lastly, the results are compared and their effectiveness measured.

3.4. Simulation Parameters

The simulation parameters for ergonomic analyses are selected based on the available aluminum panel sizes and weights in the commercial market. Table 2 presents the available market sizes of various formwork panels. In this simulation, the wall panel (600 mm × 1200 mm) was chosen for case 1, and a slab panel (600 mm × 2450 mm) chosen for case 2 and case 3. These mentioned formwork sizes and weights are taken from the Kumkand kind catalog, which is standard in size and used globally. The purpose of this study is to identify awkward postures in construction form workers using ergonomic simulation. As a result, different sized formwork slabs and wall panels were considered for human simulation in order to test the MSD effects. This study computes the OWAS and RULA scores with that specific heavy load. As a result, 13.5 kg and 27.3 kg panels were chosen for this task.

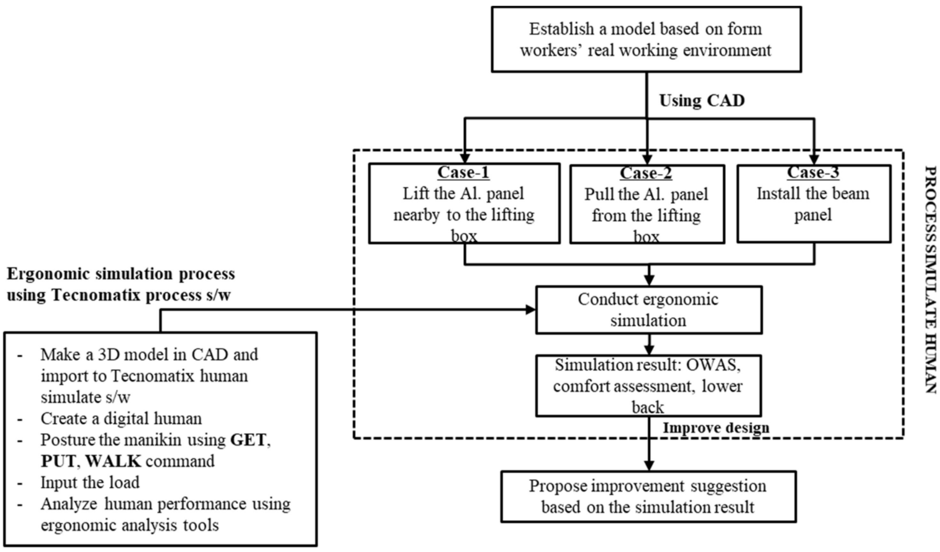

Figure 2. Ergonomic Simulation Procedure.

Table 2. Simulation parameters for Case 1, Case 2, and Case 3.

Tasks ID	Description	Dimension Length (m) × BREADTH (m)	Weight of Panel (kg)
Case-1	Wall panel	12 × 6	13.5
Case-2	Wall panel	12 × 6	13.5
Case-3	Slab panel	24.5 × 6	27.3

The Nordic Musculoskeletal Questionnaire (NMQ) survey of 92 workers from four Korean construction sites provided the human anthropometric data used in this simulation, including participants' age, height, weight, and BMI [27]. NMQ is a structured interview used to assess musculoskeletal disorders such as low back pain, neck pain, shoulder pain, and general complaints. The body mass index (BMI) 24.8 kg/m^2 is determined based on a survey on the ages (45–50 years), average height 1.74 m, and weights 75 kg of workers at four Korean construction sites [27]. As a result, this average data was utilized to calculate the MSDs discomfort for this aluminum form-work task.

3.5. Test Cases

The test cases were studied in Korean construction sites and grouped into three categories as follows:

3.5.1. Test Case 1: Lift the Aluminum Panel (AP) near the Lifting Box

The test case 1 explains the task carried out at a specific time and measures the acceptance of the posture based on a type of task and its duration (cycle) during the lifting preparation task from its storage location. It is essential to consider the duration and cycle to identify the risk of injury.

Figure 3a–d depict the worker holding and preparing to erect the aluminum wall panel (600 mm × 1200 mm) from the storage location to the lifting box. The weight of the aluminum wall panel is 13.5 kg. Awkward postures were selected from the construction site that was monitored and recorded and generated a similar 3D model for simulation to quantify the ergonomic analysis of the repetitive task. Posture 1 (P1), posture 2 (P2), posture 3 (P3), and posture 4 (P4) were simulated and the image was taken at given specific times 4.21 s, 5.21 s, 6.28 s, and 11.78 s, respectively. The distance covered by the material from the storage place to the destination was 4 m. The frequency of repetitive work has been measured for a specific period as shown in Figure 3. The person is standing at a distance of one foot from the object and lifting the object 1.5 m above the ground. Figure 3c shows the changed hand position of a person placed at the lower part of the wall panel. Figure 3d, shows the person holding the wall panel and walking from the storage place to the destination point. During this simulation, the total time taken for this task is 11.78 s and 11.4 s per panel.

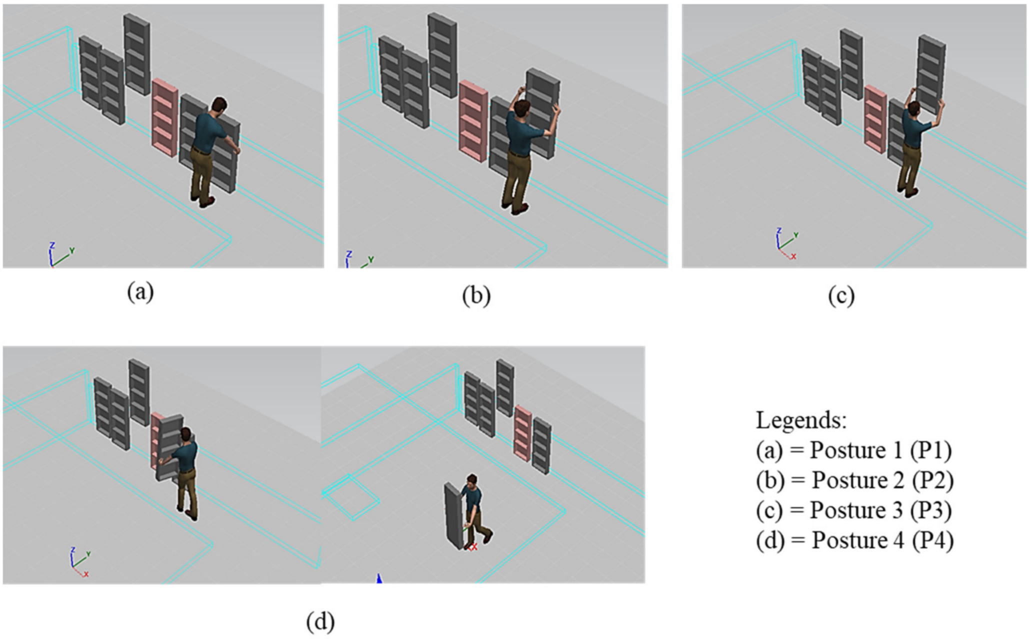

Figure 3. Test Case 1: (**a**) Holding the wall panel posture (P1), (**b**) lifting the wall panel posture (P2), (**c**) lifting and turning position posture (P3), and (**d**) holding and walking with a 13.5-kg wall panel posture (P4).

3.5.2. Test Case 2: Pull the Aluminum Panel (AP) from the Lifting Box

The test case 2 explains how much energy is needed to lift the panel from the lifting box (3 feet × 2 feet). The worker is bending to pull the panel using one hand, while the lower floor worker is pushing the panel using both hands. Under these circumstances, the simulation predicts the risk of injury and depicts the degree of posture acceptance based on specified parameters. It is necessary to identify the work injury from this task because of the critical posture obtained during site supervision. Figure 4 shows the worker holding and erecting the panel from the lifting box. The total duration for this task is 25 s. Figure 4a shows the process of lifting the formwork wall panel from the first floor to the second floor using a lifting box. Figure 4b,c shows the person pulling the wall panel from the vault, and Figure 4(P1–P3) shows the person walking and putting down the collected panel. Throughout this simulation, the total working time for the process is 0.3 min per panel. Energy consumption and OWAS are calculated based on specific parameters such as the load, period, and frequency, as presented in Table 2.

3.5.3. Test Case 3: Installing the Beam Panel

Test case 3 explains the difficulties and repetitive postures encountered during the installation of the slab formwork panel. The worker is handling and carrying a panel single-handedly without the help of an external device as shown in Figure 5a–c. Test case 3 calculates and predicts the degree of posture acceptance. It also predicts the frequency for each worker under the given BMI. This figure describes the installation of the slab panel. The worker is standing on the table, which is more than 0.7 m above the ground. Posture (P1, P2, P3, P4, P5, and P6) shows the person lifting and installing the panel with two hands. The person is bending to reach for every aluminum panel. Bent and mounted postures are photographed and simulated to quantify the ergonomic analysis.

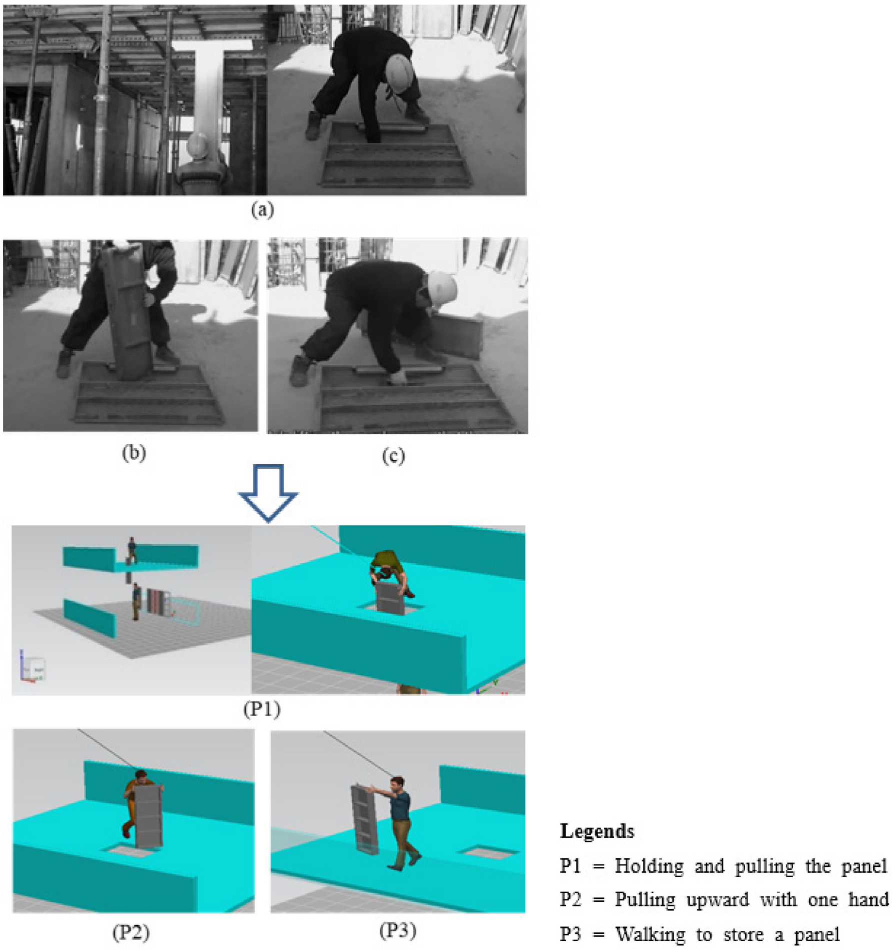

Figure 4. 3-D model-making from an on-site picture for Test Case 2: (**a**) holding and upward pulling posture, (**b**) pulling a 27.3-kg slab panel with two hand, and (**c**) pulling a panel with one hand.

3.5.4. Test Case 4: Simple Layout Modification of Test Case 2

Test case 4 aims to introduce simple and cheap solutions to reduce the prevalence of MSDs by changing the layout of the construction site. The simple modification test model (Case-4) is where the elevated bench is placed 0.9 m above ground level for pulling purposes to reduce the prevalence of MSDs among form-workers. Figure 6a,b shows the sectional 2-D elevation and 3-D model of the changed layout where the worker is standing on a lower floor, on a 0.9-m-high bench, to avoid the bent posture for a worker seated on the upper floor. The sitting position of the worker on the upper floor does not need to change during a pulling task because the distance between the object to be pulled is just enough. The simulation was performed on OWAS, RULA, and EER, based on the aforementioned simulation parameters to predict the MSD of the worker for a particular task.

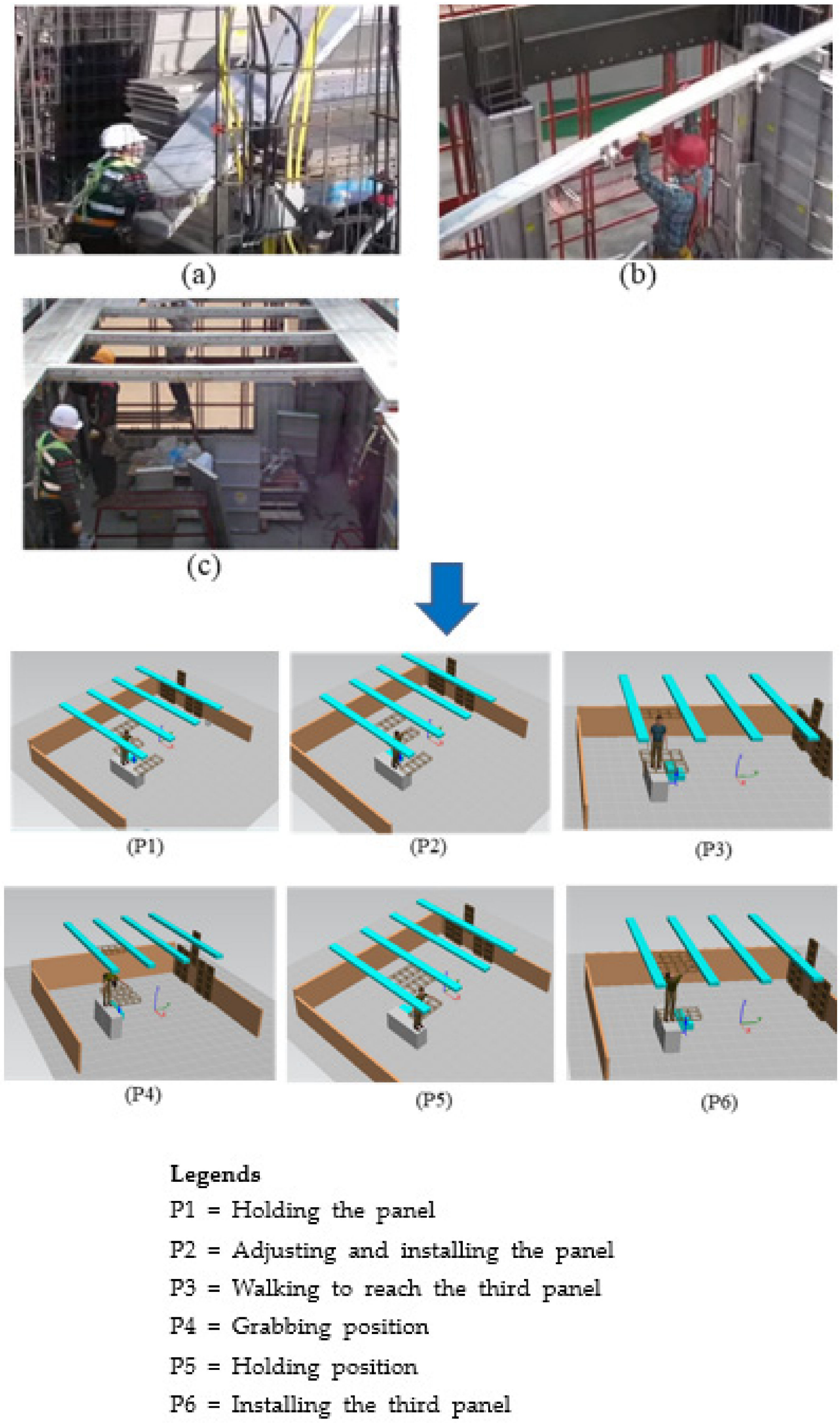

Figure 5. Model-making from real posture for ergonomic simulation (Test Case-3): (**a**) moving and placing the panel position, (**b**) installing the panel position, and (**c**) adjusting and erecting the panel position.

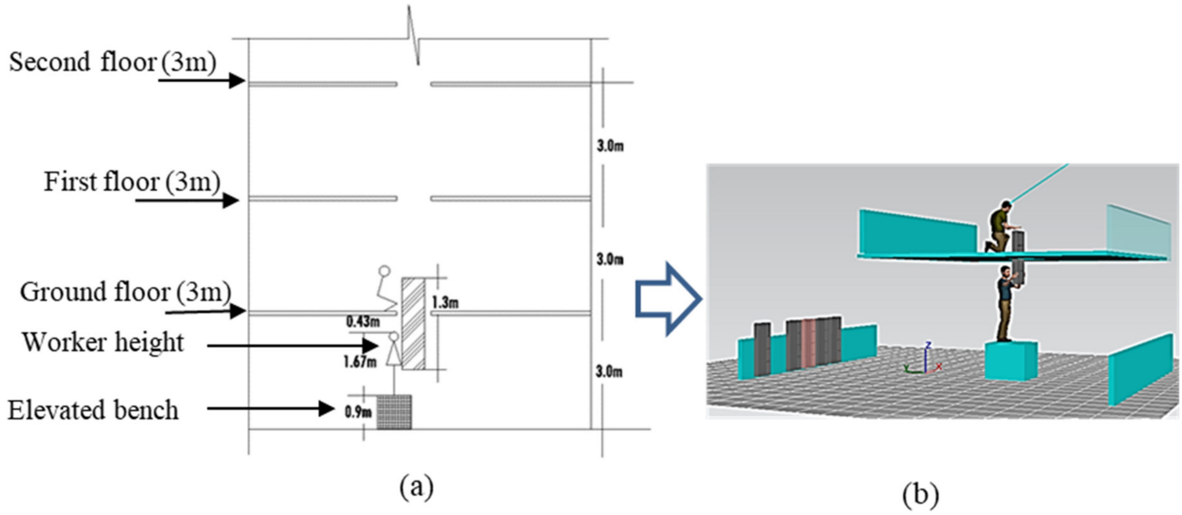

Figure 6. (**a**) Sectional 2-D elevation and (**b**) 3-D model of the changed layout.

4. Results

4.1. Identified Awkward Postures Based on Simulation

The Awkward postures P1, P2, P3, and P4 were identified for Case-1 (lift the aluminum panel near the lifting box) task from the human simulation over time as shown in Table 3. Similarly for case-2 (Pull the aluminum panel from the lifting box), task three awkward postures (P1 to P3) were identified and for case 3 (Install the beam panel) task six awkward postures (P1 to P6) were identified based on virtual simulation.

Table 3. Identified Awkward Postures for Case 1, Case 2, and Case 3.

Tasks ID	Selected Awkward Postures	Total Task Duration (s)
Case-1	P1, P2, P3 and P4	15.5
Case-2	P1, P2, and P3	12
Case-3	P1, P2, P3, P4, P5 and P6	11.7

4.2. The RULA Grand Score

The ergonomic improvement is carried out to increase the stability of the worker's posture. Hence, to validate the ergonomic condition of the worker in the lifting position, the RULA method is considered. The upper limbs (shoulder, elbow, and wrist), as well as the neck and trunk, are assessed using the RULA approach. The biomechanical and postural stresses of the task requirement are taken into account by this tool. The posture is examined in terms of muscle usage frequency and the intensity of force [23]. Figure 7 shows lifting postures P1, P2, P3, and P4 with their corresponding RULA scores (Case-1) of 2, 4, 4, and 7, indicating that the position is not within the permitted range and that the worker is experiencing biomechanical stress. The positions of the arms, wrists, neck, chest, and legs are all scored. As a result, workstation designs must be redesigned to be more ergonomic. Figure 7 demonstrates that the RULA scores (Case-2) for the pulling postures (P1, P2, and P3) are 2, 3, and 4, indicating that the position is undesirable and needs to be changed. Figure 7 shows that the RULA scores (Case-3) for the installing postures (P1, P2, P3, P4, P5, and P6) are 3, 3, 7, 7, 5, and 4, which indicates that the postures are not within the recommended range and are causing biomechanical stress. The overall score runs from 1 to 7, with 1 representing the best posture and 7 representing the worst posture. Higher RULA scores indicate lower confidence in work postures and higher risks, and lower RULA scores indicate higher confidence and lower risks associated with the working posture (see Table 1). The RULA score (1–2) is the only acceptable parameter, as shown in Table 1.

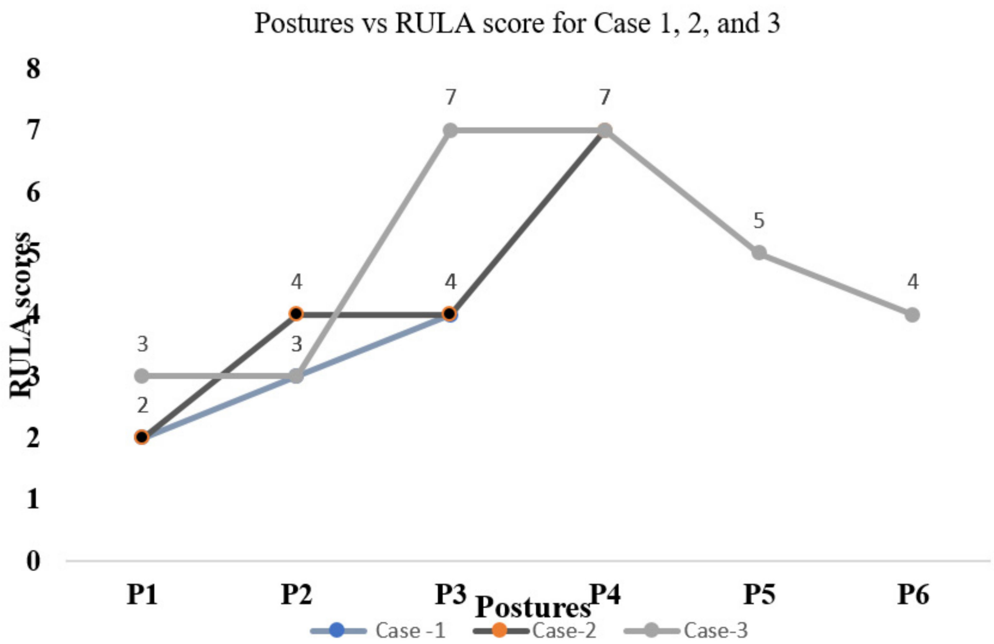

Figure 7. RULA scores for Case 1, Case 2, and Case 3 (P1, P2, P3, P4, P5, and P6) postures.

4.3. The OWAS Score

Using the Tecnomatix human simulation software program, the OWAS score is estimated to enhance the working posture, as illustrated in Tables 3–5. The back, arms, leg, weight, and head categories, as well as their respective OWAS scores, are listed in the Table. Table 4 results (Case-1) reveal that OWAS scores are a combination of 2122-1, with an erect body, both hands beneath the shoulders, standing on both feet, with a 13.5-kg load for the posture (P1). This position action category was 2, which is regarded as having a negative impact and requiring immediate remedial actions. Similarly, Table 4 depicts Case-2 and shows the OWAS scores for poses P1, P2, and P3, which indicate a straight back, both hands beneath the shoulders, walking, and a load of 13.5 kg for the posture (P2, P3), both of which are categorized as undesirable and requiring correction. Table 5 reflects Case 3 and shows the OWAS score for six postures ranging from P1 to P6. The most common OWAS awkward posture was bent backward, both arms below the shoulder, in the standing position, with a load of more than 20 kg, and a twisted head position for postures P1, P2, P5, and P6. The action falls into three categories, all of which are harmful and require preventive action. Table 1 was used to compute and explain the action category score [5].

Table 4. Counting the OWAS score for Case 1 and Case 2.

	Description		Case 1				Case 2		
	Postures	**Score**	**P1**	**P2**	**P3**	**P4**	**P1**	**P2**	**P3**
Back	Straight	1							
	Bent	2	2	1	2	1	4	2	1
	Twisted	3							
	Bent and twisted	4							
Arms	Both arms below the shoulder	1							
	One arm at or above shoulder level	2	1	3	3	3	1	3	3
	Both arms at or above shoulder level	3							
Leg	Seated	1							
	Standing	2							
	Uni-podal, straight leg	3							
	Knees bent	4							
	Uni-podal support, bent	5	2	2	7	7	2	7	7
	Kneeling or squatting	6							
	walking	7							
	Sitting with legs and buttocks	8							
	Additional postures in which legs give no support	9							
	Crawling or climbing	0							
Weight	<10 kg	1							
	10 kg–20 kg	2	2	2	2	2	2	2	2
	>20 kg	3							
Head	Free	1							
	Bent forwards	2							
	Bent to the side	3	1	1	1	1	1	1	1
	Dent backwards	4							
	Twisted	5							
Total	OWAS score		2122-1	1322-1	2372-1	1372-1	4122-1	2372-1	1372-1
	Action category		2	1	3	1	2	3	1

4.4. Estimation of the Energy Expenditure Rate (EER)

The EERs for three cases are estimated in Table 6 based on the task cycle and frequency. This technique identifies the hand exertions per work cycle and the number of hand exertions associated with forces and adverse postures. For case 1, the task was classified into four subtasks (lift, hold, and push) with a load of 13.5 kg, resulting in an EER of 8.8 kcal/min. The estimated EER for this task (8.8 Kcal/min) is higher than the recommended value of 8.2 kcal/min, which indicates an increase in the risk of fatigue injury. This work needs to be changed, which means to reduce the rate of energy expenditure, which entails minimizing the movement of the whole body (lifting, walking, climbing, etc.), reducing the load of the object, and the occurrence cycle of lifting operations. As the frequency increases from 1 to 7, fatigue increases, causing the rate of energy expenditure to increase. Similarly, the estimated EER for case 2 task (pull task) and case 3 task (install task) are 7.33 kcal/min, and 6 kcal/min, which is above the recommended value of 7 kcal/min and 5.8 kcal/min, respectively, indicating an increased risk of damage due to fatigue.

Table 5. Counting the OWAS score for Case 3.

	Description		Case-3					
	Postures	**Score**	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**
Back	Straight Bent Twisted Bent and twisted	1 2 3 4	2	2	1	2	2	2
Arms	Both arms below the shoulder One arm at or above shoulder Level Both arms at or above shoulder Level	1 2 3	1	3	1	1	1	3
Leg	Seated Standing Unipodal, straight leg Knees bent Unipodal support, bent Kneeling or squatting Walking Sitting with legs and buttocks Additional postures in which legs give no support Crawling or climbing	1 2 3 4 5 6 7 8 9 0	2	2	7	2	2	2
Weight	<10 kg 10–20 kg >20 kg	1 2 3	3	3	3	3	3	3
Head	Free Bent forwards Bent to the side Dent backwards Twisted	1 2 3 4 5	1	4	1	4	4	4
Total	OWAS score		2123-1	2323-4	1173-1	2123-4	2123-4	2323-4
	OWAS Action category		3	3	1	3	3	3

Table 6. Energy expenditure rate for Case 1, Case 2, and Case 3.

Description	Details	Load (kg)	Cycle (min)	Frequency	Total Task Energy	Energy Expenditure Rate (kcal/min)
Case-1	Lifts	13.5	<1	**7**	3	8.8 (above recommended value of **8.2** kcal/min)
	Lifts	13.5	<1	6	2.4	
	Holds	13.5	<1	4	0.2	
	pushing	13.5	<1	4	2.5	
Case-2	Push pull	13.5	<1	**12**	4.9	7.33 (above recommended value of **7** Kcal/min
	Carries	13.5	<1	10	1.8	
	Arm length at sides, both	13.5	<1	4	0.27	
	Walks	13.5	<1	5	0.4	
Case-3	Lateral arm work	27.3	<1	1	0.2	6 (above recommended value of **5.8** Kcal/min
	Holds	27.3	<1	4	0.2	
	Lateral arm work	27.3	<1	4	0.7	
	Walks	27.3	<1	3	0.1	
	Carries	27.3	<1	4	0.6	
	Lateral arm work	27.3	<1	**15**	15	

4.5. Simple Layout Modifications Test Model (Case-4) Results

Based on the simulation results, an elevated bench was placed for easy lifting, which is cheap, and simple layout changes were performed for Case-2 to improve workers' MSD. Via comparisons with the standard RULA chart from Table 1, Figure 8 illustrates the RULA score of lifting the postures of P1, P2, P3, and P4, which are 2, 1, 1, and 2, respectively, indicating that the position is within the acceptable range and does not place the worker under biomechanical stress. Table 7 shows the OWAS scores for postures where 2122-1 (P1), 1322-1 (P2), 1322-1 (P3), and 1372-1 (P4) were identified, with the action category 2 for posture P3 indicating that corrective activities are not required right away. The working posture is defined as having a straight back, both arms above shoulder level, maintaining an upright position, and a weight load of 13.5 kg, all of which indicate a safe posture. Table 8 presents estimates of the energy expenditure rate for case 4 that were classified into four subtasks (push, carry, arm length at sides, and walk). When the frequency rate is reduced from 12 times (Case-2) to 10 times (Case-4), the energy expenditure rate is 6.5, which is less than the suggested threshold of 7 Kcal/min, indicating that there is no risk of MSD or damage. The use of the elevated bench eliminates the physical loading of the twisting body, which is believed to minimize the risk of injury and pain. The use of an elevated bench to transfer material is expected to boost productivity since it eliminates the need to twist the lifting stance.

Table 7. Counting the OWAS score for Case 4.

	Description		**Case 4**			
	Postures	**Score**	**P1**	**P2**	**P3**	**P4**
Back	Straight	1				
	Bent	2	2	1	1	1
	Twisted	3				
	Bent and twisted	4				
	Both arms below the shoulder	1				
Arms	One arm at or above shoulder level	2	1	3	3	3
	Both arms at or above shoulder level	3				
	Seated	1				
	Standing	2				
	Uni-podal, straight leg	3				
	Knees bent	4				
Leg	Uni-podal support, bent	5	2	2	2	7
	Kneeling or squatting	6				
	walking	7				
	Sitting with legs and buttocks	8				
	Additional postures in which legs give no support	9				
	Crawling or climbing	0				
	<10 kg	1				
Weight	10 kg–20 kg	2	2	2	2	2
	>20 kg	3				
	Free	1				
	Bent forwards	2				
Head	Bent to the side	3	1	1	1	1
	Dent backwards	4				
	Twisted	5				
Total	OWAS score		2122-1	1322-1	1322-1	1372-1
	Action category		2	1	1	1

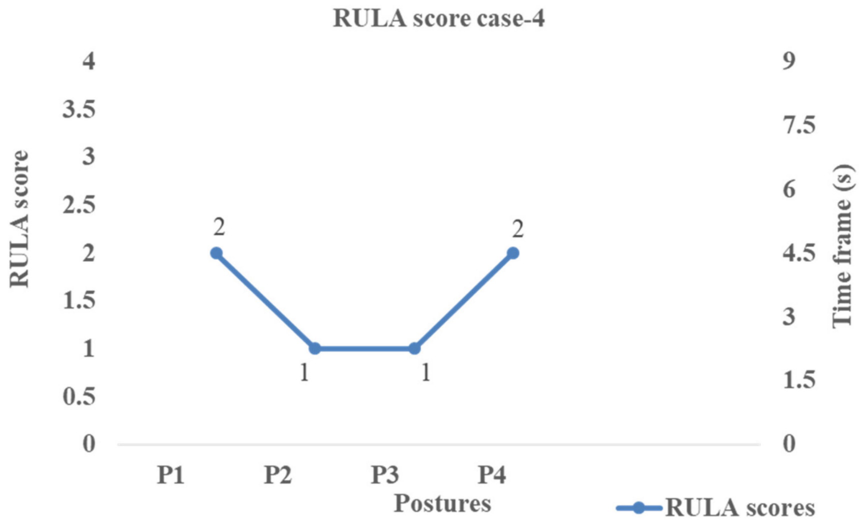

Figure 8. RULA Scores for Case 4 (P1, P2, P3, and P4) postures.

Table 8. Energy expenditure rate (EER) for Case 4.

Description	Details	Load (kg)	Cycle (min)	Frequency	Total Task Energy	Energy Expenditure Rate (kcal/min)
Case-4	Push pull	13.5	<1	10	3.5	6.5
	Carry	13.5	<1	10	1.8	(Below the
	Arm length at sides, both	13.5	<1	4	0.27	recommended value of
	Walk	13.5	<1	5	0.4	7 kcal/min)

5. Discussions

The current study identifies the three awkward postures (Case 1, Case 2, and Case 3) of aluminum form workers and evaluates the ergonomic score (RULA, OWAS, EER) and suggest simple preventive solution. The findings of the study showed that the existing awkward postures were unsafe for construction workers and found acceptable posture for modified workstation. Based on the findings, the following implications can be drawn:

There are not many remarkable ergonomic studies of Aluminum form-worker MSDs and their work environments in the construction industry. However, there are many suggestions and countermeasures for the "push" and "hold" operations of general construction tasks that are somehow related to the normal activities such as push and pull of form-workers. Push and hold operations of various construction tasks confirm worker injury and stress from repetitive tasks [28]. Every construction task is unique and complex, with a varying time frame. In the case of workers' MSDs, time duration is extremely important. As a result, this research considers both the duration and frequency of an Aluminum form-workers' task. As a result, this study helps to normalize the injury rate in future. Existing preventive solutions suggested that altered workstation layouts are one of the ways to reduce MSD stress on workers, which is consistent with the simulation results of this study. The most problematic working postures found for the three tasks were twisting the body, walking while carrying loads, and maintaining the arm position. There were three observed cases with the OWAS, RULA, and EER scores. The 2372-1 (Case-1), 2122-1 Ccase-1), 4122-1 (Case-2), 2372-1 (Case-2), 2123-1 (Case-3), 2323-4 (Case-3), and 2123-4 (Case-3) strenuous postures were identified and work improvements were discussed. This previous research backs up the similar finding on general workers' manual material handling such as pull and push tasks [28]. However, this study focuses on construction form workers and contributes to addresses MSDs such as awkward postures while installing and pulling the panel, as described in Cases 1 and 2.When the operator adjusts, lifts, and pulls the wall and slab panels, certain awkward postures emerge. To avoid awkward postures, workers had to either modify their body positions or upgrade their workstations. Previous study results also suggested to re-examine and redesign the work station to reduce the MSDs [29]. Hence, this study remodels the workstation using an elevated bench to avoid twisting the body. According to the authors, the OWAS and RULA methods are suitable for whole-body movements and reliable for the analysis of tasks on the construction site. The previous study proved that RULA method is one of the useful tool to assess the MSDs on pulling and manual tasks [30]. The findings of comparisons of the OWAS and RULA scores and EER rates for four cases are shown in Table 9. Cases 1, 2, and 3 were found to be risky for workers undertaking specified tasks, which confirms the findings of previous studies [8,31,32]. Therefore, the Case 4 design was implemented and simulated, and an ergonomic analysis score was obtained, demonstrating that the changed layout and reduced task frequency are suitable for the workers of the specific task. According to previous studies, muscle tension increases over time; therefore, the duration and frequency of the exertion are taken into account throughout the simulation [33,34]. The study focused at three test instances, which means they were recurrent events associated with high long-term risks.

Table 9. Comparison of results between OWAS, RULA, and EER.

Analysis	**CASE-1**				**CASE-2**			**CASE-3**						**CASE-4**			
Postures (P1 to P6)	P1	P2	P3	P4	P1	P2	P3	P1	P2	P3	P4	P5	P6	P1	P2	P3	P4
OWAS (Action category)	2	1	3	1	2	1	3	2	2	1	3	3	4	2	1	1	1
RULA	2	1	1	2	2	3	4	3	3	7	7	5	4	2	1	1	2
Metabolic energy expenditure (kcal/min) (recommended value)	8.8 (above recommended value (8.2)				7.33 (above recommended value) (7)			6 (above Recommended value) (5.8)						6.5 (below 7 recommended value)			
Time taken	<1 min				<1 min			<1 min						<1 min			
Remarks	Not safe for workers (HIGH)				Not safe for workers (MOSTLY HIGH)			Not safe for workers (HIGH)						Safe for workers (LOW)			

By conducting ergonomic assessments in a virtual environment as opposed to on-site assessments, the design of the workplace and operations can be modified to assess and analyze the impact of various designs on ergonomic risks. Human models and motions also enable updating motions and tasks based on results and re-evaluating to ensure safe actions. This method allows for the comparison of various scenarios in order to mitigate potential risks and improve safety by selecting the most feasible and implementing engineering interventions. However, while it is possible to conduct assessments in the physical workplace through empirical observation and measurements (conventional ergonomic approach), only existing conditions can be evaluated, making it difficult to explore different designs and develop applicable interventions. Moreover, the measurements and observations required for data collection can be completed in the virtual environment, saving time and resources. This kind of ergonomic risks in the virtual environment can be useful for redesigning ongoing operation and workplaces during early stages construction phase.

To reduce MSD, more preventive action on simulations may be desirable. Another constraint is that the weight of the formwork panels for push, pull, and install jobs can vary significantly depending on the available resources. Due to its standard size, the weight of the panel cannot be changed; however, the frequency of lifting activities can be changed to reduce muscular strain. Other postures with varied formwork weights should be investigated in the future. The stimulation of complicated construction environments allows for the prediction of varying levels of complexity and the application of simple methods to analyze the effectiveness of workers' MSD. OWAS has limitations on difficult postures; therefore, the use of supplementary methods, such as RULA and EER, which are designed for upper extremity analyses, compensates for OWAS' flaws. Because of the difficulty in associating the other ergonomic technique with the construction equipment, it was not pursued further. Overall, the results indicate that integrating human ergonomic analysis and workplace visualization can result in higher adoption of this practice where simulation modeling requires less time and effort for evaluation.

6. Conclusions

This study makes a significant contribution by providing an ergonomic risk assessment of form-workers' MSD, converting real-world scenarios to simulated environments, and offering simple MSD prevention strategies. Lift, pull, and install tasks on construction form-workers' overtime in various scenarios and loads are done in three cases. The ergonomic analysis of muscle strains of aluminum form-workers for repetitive postures was analyzed and measured in this study. OWAS, RULA, and EER ergonomic analysis scores were calculated. According to the findings of this study, the scores of all three techniques, RULA, OWAS, and EER, indicated the unsafe, unacceptable human postures in the three-precedent form-workers' test cases, and it was advised that the workstation architecture be changed. A simulation in which a simple elevated bench arrangement was adopted, which contributed to the decrease in the prevalence of MSDs, and an ergonomic study suggested a safe posture with no adverse effects on the workers. These comparisons can be used to help with a certain postural trait. These test scenarios can be used to forecast how long job designs will last for job readiness. To overcome and eliminate issues and restrictions, more research and studies are needed. The study will be expanded in the future to simulate and quantify semi-automated and completely automatic instruments used by form-workers throughout transporting and installation procedures.

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