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INTEGRATED ERGONOMIC AND PRODUCTIVITY ANALYSIS FOR PROCESS IMPROVEMENT OF PANELISED FLOOR MANUFACTURING

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ABSTRACT
Workers in the construction manufacturing industry are often exposed to labour-intensive tasks with ergonomic risks such as awkward body posture, forceful exertion, and repetition motion. Due to the increased productivity and increased repetitive motions resulting from improvement initiatives implemented in offsite construction, the investigation of ergonomic risks associated with these changes is needed. In this context, this paper explores an existing panelised floor production line aiming to minimize its ergonomic risks while improving its current productivity rate. Information on human body motion and productivity are extracted from video recordings. The ergonomic risks associated with specific tasks are identified using an existing ergonomic risk assessment tool (i.e., Rapid Entire Body Assessment (REBA)). The information extracted from the simulation model pertaining to ergonomic risks and productivity supports the decision-making process and aids in the prioritization of changes to improve the working environment.

Keywords: workstation design, work measurement, ergonomics, decision support system, productivity improvement

1. INTRODUCTION

Workers' unsafe behaviour is responsible for 80% of construction accidents (Li et al. 2015). In 2017, the manufacturing and construction industries accounted for the second and fourth highest number of diseases and lost time injuries, and the second and first highest number of fatalities among all industries in Canada, respectively (Association of Workers' Compensation Boards of Canada (AWCBC) 2019). Construction and manufacturing workers are often exposed to the three primary causes of work-related musculoskeletal disorders (WMSDs): awkward body posture, forceful exertion, and repetitive motion (Canadian Centre for Occupational Health and Safety 2017; Public Services Health & Safety Association (PSHSA) 2010; Xu et al. 2012). WMSDs, which are often caused by bad workplace ergonomics, are responsible for higher absenteeism and injury rates thus resulting in significant loss of productivity and increased production cost (Botti et al. 2017a; Rajabalipour Cheshmehgaz et al. 2012). Hence, the investigation of physical demands of body motion is needed for workstation design and manufacturing processes in offsite construction facilities to minimize WMSDs and reduce any negative impacts on company productivity.

Several approaches have been developed to identify and assess ergonomic risks by analysing two main factors: (a) body posture (e.g., body angles, force load, and interaction between the human body and other working elements such as tools and machines) (Golabchi et al. 2016), and (b) biomechanical analysis, which focus on internal and musculoskeletal loads, and stresses on joists (Armstrong et al. 1996). For instance, Rapid Entire Body Assessment (REBA) (Hignett & McAtamney 2000), Rapid Upper Limb Assessment (RULA) (McAtamney & Nigel Corlett 1993), and Ovako Working Posture Analysing System (OWAS) (Karhu et al. 1977) focus on body posture analysis, while 3D Static Strength Prediction Program (The University of Michigan Center for Ergonomics 2017) and OpenSim (OpenSim 2019) use biomechanical analysis as their primary assessment approach. In research studies, REBA and RULA are often applied to conduct ergonomic risk assessment (Li 2017).

Meanwhile, the construction industry is known for low productivity rates (Ikuma et al. 2011). One approach to improve lead times and productivity for construction projects is to shift to offsite construction and utilise lean construction principles (Abbasian-Hosseini et al. 2014; Dotoli et al. 2015; Jia et al. 2013; Yu et al 2013). To ensure continuous improvement of productivity, many facilities focus on continuous improvement initiatives (Aqlan and Al-Fandi 2018). These initiatives need to consider the impact of any changes made on the business, including the cost, productivity, ergonomic, and public perception implications of making changes to the production process. The considerations when determining if a process change will have desirable effects can be conflicting, making it difficult for management to determine which changes should be implemented. Although implementation of lean construction principles results in improved productivity, studies indicate that it also leads to an increase in physical workload and motion repetition, which are factors associated with WMSDs (Botti et al. 2017a; Colombini et al. 2002; Hochdörffer et al. 2018; Mossa et al. 2016). Investigating the implementation of lean principles in industrialized construction is thus needed to explore its impacts not only on productivity, but also on ergonomic risks.

Few studies investigate ergonomic risks in industrialized construction. Inyang et al. (2012) and Abaeian et al. (2016a) propose a framework to perform ergonomic assessment on a residential construction production line. The application of three-dimensional (3D) models to automatically identify and evaluate awkward body posture to reduce WMSDs in manufacturing plants is explored by Golabchi et al. (2015) and Li et al (2017a). Li et al. (2017b) investigate muscle activity during repetitive material handling, which is also explored by Abaeian et al. (2016b). An improved physical demand analysis based on ergonomic risk in manufacturing construction is developed by Li et al. (2019). The application of ergonomic principles in the design of work places to reduce injury rates and exposure to ergonomic risks while increasing productivity is explored in several studies (Battini et al. 2011, 2015; Bortolini et al. 2018; Botti et al. 2017a,b; Golabchi et al. 2018; Ikuma et al. 2011; Mossa et al. 2016).

In this paper, an existing panelised floor manufacturing line is investigated with the objective of minimizing ergonomic risks while maintaining/increasing the production rate.

2. METHODOLOGY

This study combines two common research areas in offsite construction and simulation to recommend decision alternatives that consider not only the productivity and performance aspects of the proposed change, but also the effect on the ergonomic risk for the workers who are expected to complete these tasks. This analysis is done by integrating the REBA score for the various postures required to complete a floor construction task into a simulation model that represents the production times and possible task alternatives for the process. The methodology can be broken down into three areas, which are discussed in more detail in the following sections.

2.1. Production Observations and Simulation

To carry out a full analysis of the production activities for the floor panel construction process, it was first necessary to observe and understand the current process. This was done by in-person observations, as well as through video cameras installed in the facility. Workers were notified of the study and were aware of the cameras. It was communicated to the workers in the area that the analysis was for the process and not for critique of their work habits.

Throughout the observations, timings for individual tasks, differences in the way tasks were being completed, and the number of people working on a task at a time were recorded. This information was used to create a simulation model of the process and to test proposed improvements for the purposes of productivity increase, as detailed in a previous study (Ritter et al. 2016). The production alternatives shown in Table 1 were identified for investigation in this study, as they have been selected as possible productivity improvement measures that involve a change in the way people complete the production tasks.

Table 1: Identified Production Alternatives

Task	Current State	Possible Alternative
Place joists on jig	One person placing large joists (half of the time)	Require two people to place large joists
Apply glue on joists	Apply glue with automated multi-function bridge	Apply glue manually when multi-function bridge is being utilized on the other jig
Place sheathing on joists	Sheathing placed with vacuum lift (1 person)	Sheathing delivered with material delivery bridge
	Sheathing placed with vacuum lift (2 people)	

2.2. Ergonomic Risk Assessment

As identified through literature review and discussions with industry partners, the ergonomic risks associated with a production change are a priority factor, along with the cost and production interruption, when deciding whether to implement the change. An ergonomic assessment is performed using REBA to identify the ergonomic risks associated with the current process to which the proposed changes will be compared in terms of ergonomic risks and productivity. REBA is selected in this study as its total score encompasses information on upper and lower limbs as well as force load and coupling, thus covering the majority of human body movements encountered in the construction task explored in this paper (Hignett & McAtamney 2000).

The inputs for the REBA assessment are collected based on observation of workers' postures and motions extracted from video recordings of the panelised floor manufacturing process. Video recording is a cost-effective approach to acquire posture-based information and it also has the advantage of not disrupting the workforce during data collection (Li & Buckle 1999). An example of the REBA assessment conducted in this study is presented Figure **1**. The overall REBA score will be calculated in the simulation model using the formula shown in Equation 1, where d_i is the duration of each task. According to the REBA score, the risk level of a task and necessity of action is obtained as summarized in Table 2.

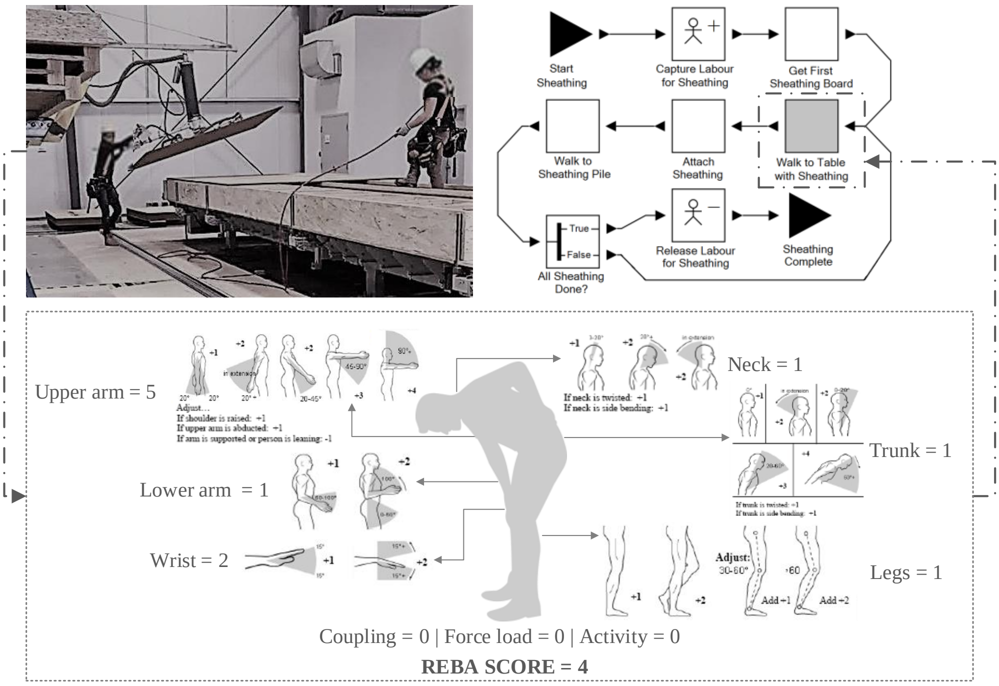

Figure 1: REBA score of walking to table with sheathing task

$$REBA_{sim} = \frac{\sum_{i=1}^{n}(REBA_i \times d_i)}{\sum_{i=1}^{n} d_i} \quad (1)$$

Table 2: REBA score, risk level, and action (adapted from Hignett & McAtamney 2000).

REBA Score	Risk Level	Action
1	Negligible	Not necessary
2-3	Low	May be necessary
4-7	Medium	Necessary
8-10	High	Necessary soon
11-15	Very high	Necessary now

2.3. Implementation Recommendations for Production Alternatives

Once a productivity impact and an ergonomic risk assessment were both complete for the current and possible future alternatives for the identified tasks of the floor panel production process, a more complete quantification of the impact of the proposed changes can be made. To determine a thorough estimate of the effect that a change may have on the production line, it is necessary to combine the ergonomic risk factor with the productivity change. To do this a detailed simulation model with the times for individual activities within each task was made to include the REBA score along with the time to complete the task, so that an overall idea of the extent to which each score was experienced for the variable tasks could be realized. The ergonomic risk as well as the expected average time to complete the task for each alternative considered in this study are detailed in Table 3.

Table 3: Ergonomic risk and production time

Task	Maximum Postural Hazard Score (REBA)	Expected Average Task Time (mins)
Place joist with one person (done half of the time)	10	0.4
Always place joist with two people	10	0.4
Always use MFB to apply glue	1	3.8
Glue manually when MFB is in use	6	5.0
Place sheathing with one person using a vacuum lift	6	1.3
Place sheathing with two people using a vacuum lift	8	0.9
Place sheathing with two people using material delivery bridge	4	0.6

As observed in Table 3 and Figure 2, a relationship between the number of workers performing a task and the task's REBA score is not identified in this paper. For instance, having one or two people placing the joists in the workstation did not result in different REBA scores. This happens because the weight of the joists is greater than 10 kgs, even when shared between two workers, and thus it receives the highest score in the load/force category of REBA. The REBA score might be different in cases of lighter materials. Furthermore, more than one person can be sharing a

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task but not necessarily performing the same subtask, as illustrated in Figure 2 (right side), which results in the distinct REBA scores of each worker. It is important to clarify that the maximum REBA score is used to conduct the analysis in this study.

Figure 2: Samples of workers' body movements used to conduct ergonomic analysis.

Workers' behaviour and movement preferences are also found to be a key aspect when conducting ergonomic risk analysis, as exemplified in Figure **3**, which illustrates one and two workers attaching the sheathing. While the worker in the image on the left is standing with his/her legs slightly angled, the worker in the image on the right is squatting to perform the activity, which results in a higher REBA score due to the angle of his/her legs and thus increasing the risk of WMSD, especially if accounting for the fact that this posture is repeated several times until completion of the task. This shows the importance of providing training for workers with focus not only on the operational aspect of the task but also on how to perform it minimizing ergonomic risks. To reduce the discrepancy between the REBA scores of different workers, standardization with respect to how to conduct tasks in an ergonomic manner is recommended.

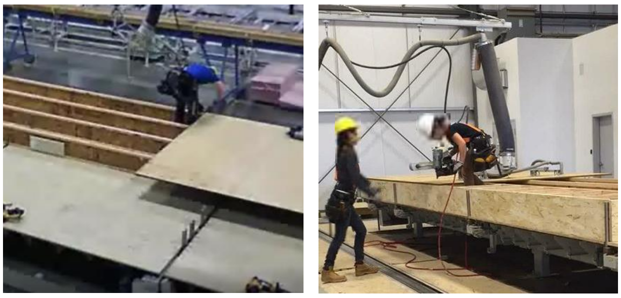

Figure 3: Attaching sheathing with one worker (left) and two workers (right).

2.4. Quantification of Results

In the case of competing goals, it may be necessary to apply a metric to simplify the process of selecting a final decision from the possible alternatives. First, the factors are normalized using equation 2 and 3, where F_E is the ergonomics factor, F_P is the productivity factor, P_{sim} is the simulated productivity for the scenario, and P_{goal} is the goal productivity, which was 2.1 panels per hour.

$$F_E = \begin{cases} 1, if\ REBA_{sim} \leq\ 3 \\ 1 - \frac{1}{8}(REBA_{sim} - 3), if\ REBA_{sim} >\ 3 \\ 0, if\ REBA_{sim} \geq\ 11 \end{cases} \quad (2)$$

$$F_P = \begin{cases} \frac{P_{sim}}{P_{goal}}, if\ P_{sim} <\ P_{goal} \\ 1, if\ P_{sim} \geq\ P_{goal} \end{cases} \quad (3)$$

As can be seen by these equations, F_E is 1 (meaning the ergonomics goal is met), when the REBA score is between 1 and 3 and 0 when there is a high ergonomic risk, or a REBA score of 11 or above. Between these values, F_E is assumed to be a linear incremental risk factor. Similarly, F_P is 1 when the productivity goal is met or exceeded, while an F_P of 0 would indicate that no productivity change was accomplished.

Next, the factors are combined. For this scenario, the two factors are assumed to be equal. For other cases where there are multiple factors and they may not have equal weights on the final decision, surveys of the stakeholders to determine the relative weighting of each factor may be required. The formula for the final metric, or decision factor (F_D) is shown in equation 4.

$$F_D = 0.5F_E + 0.5F_P \quad (4)$$

A decision factor of 1 shows that both goals of minimizing the REBA scores of the activities and improving the productivity are met.

3. RESULTS

When ergonomics are taken into consideration along with other common decision making factors, such as capital cost, operating cost, implementation time, and expected productivity increase, it is found that the decision as to whether or not to implement a production alternative may change, or further investigation may be required before an alternative can be recommended for implementation. The results for the total productivity and average REBA score for each of the twelve alternatives created by combining the station alternatives in various ways can be seen in Table 4.

Based on these results, it can be determined that options 3, 6, 9, and 12 result in the highest productivities while options 3, 6, 4, and 10 result in the lowest REBA scores. In this case, two of the most ideal options for each of the considerations overlap, so options 3 and 6 are recommended; however, options 9 and 12 are also considered ideal as they result in similar productivities with a minimal increase in REBA score. It is important to also note that the two options with the lowest REBA scores (options 4 and 10) also result in the lowest productivities of all of the options. Due to the minimal difference between the REBA scores for these options and the REBA scores for the options with the highest productivities, these two options are not recommended for implementation. These results also illustrate the importance of analysing how the production changes affect the two variables together. An example of this is

Table 4: Simulation results for suggested production alternatives

Option	Place Joists Method	Gluing Method	Sheathing Method	Total Productivity (panels/hour)	Average REBA Score	Decision Factor (F_D)
1	Place with one person (50% of panels) and two people (other 50% of panels)	Always use MFB to apply glue	Place with one person using a vacuum lift	1.737	2.881	0.91
2			Place with two people using a vacuum lift	1.859	3.890	0.89
3			Place with two people using a material delivery bridge	2.054	2.083	0.99
4		Glue manually when MFB is in use	Place with one person using a vacuum lift	1.473	1.957	0.85
5			Place with two people using a vacuum lift	1.985	2.546	0.97
6			Place with two people using a material delivery bridge	2.137	2.016	1.00
7	Always place joists with two people	Always use MFB to apply glue	Place with one person using a vacuum lift	1.740	3.049	0.91
8			Place with two people using a vacuum lift	1.870	4.070	0.88
9			Place with two people using a material delivery bridge	2.063	2.288	0.99
10		Glue manually when MFB is in use	Place with one person using a vacuum lift	1.473	1.957	0.85
11			Place with two people using a vacuum lift	2.004	2.724	0.98
12			Place with two people using a material delivery bridge	2.165	2.185	1.00

the difference between option 4 and option 6. Option 6 may be assumed to have a lower overall REBA score due to the lower score of the sheathing method (the differentiating activity) chosen in option 6; however, the simulation analysis shows that option 4 actually results in the lower REBA score of the two options due to the difference in the number of people and duration of the two different methods of installing the sheathing.

While, in this scenario, the best options for implementation can be determined by looking at the simulated results for the overall productivity and REBA score, the combined decision factor (F_D) can be utilized to make this conclusion faster and clearer. As seen in Table 4, options 6 and 12 satisfy both goals, as evidenced by their decision factor of 1, while options 3 and 9 are reasonable options as well, both with a factor of 0.99.

Future work for this analysis will involve investigating the calculation of the decision factor further. Currently, a REBA score of 4, or one point above the acceptable score range will decrease the decision factor by the same point as a productivity that is 12.5% below the goal productivity. Additionally, the effect of the REBA scores on the decision factor are currently being considered as linear, which requires further investigation.

4. CONCLUSION

The case study covered in this exercise shows that, when compared to considering only the effects on productivity that are made by process changes, including the ergonomic impacts of a process change will allow management at offsite construction facilities to make more informed decisions.

While the productivity impacts, cost, ergonomic influence, production interruption, and other factors are all important when making a decision to change a process, it is difficult to determine the relative importance of each consideration and the overall collective impact they have on the operations of a facility. In this case, the ergonomic and productivity impact have been considered together to analyse the decision alternatives and, in the future, more variables can be added to continue to simplify the decision-making process for management at these facilities. Another future improvement to the model will be to consider the weight that each decision variable has in the final decision.

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REFERENCES

Abaeian H., Inyang N., Moselhi O., Al-Hussein M., El-Rich M., 2016a. Ergonomic Assessment of Residential Construction Tasks Using System Dynamics. Proceedings of the 33rd Annual International Symposium on Automation and Robotics in Construction, pp. 258-256. July 18-21, Auburn, AL, USA.

Abaeian H., Moselhi O., Al-Hussein M., 2016b. System Dynamics Model Application for Ergonomic Assessment of Manual Material Handling Tasks. Modular and Offsite Construction Summit Proceedings, pp. 240-247. September 29-October 1. Edmonton, AB, Canada.

Abbasian-Hosseini S., Nikakhtar A., Ghoddousi P., 2014. Verification of Lean Construction Benefits through Simulation Modeling: A Case Study of Bricklaying Process. KSCE Journal of Civil Engineering. 18(5):1248-1260.

Armstrong T., Buckle P., Fine L., Hagberg M., Haring-Sweeney M., Martin B., Punnett L., Silverstein B., Sjogaard G., Theorell T., Viikari-Juntura E., 1996. Musculoskeletal Disorders: Work-related Risk Factors and Prevention. International Journal of Occupational and Environmental Health. 2:239–246.

Association of Workers' Compensation Boards of Canada (AWCBC). 2018. 2017 Statistics. Available from: awcbc.org/?page_id=14 [accessed 14 April 2019].

Aqlan F., Al-Fandi L., 2018. Prioritizing process improvement initiatives in manufacturing environments. International Journal of Production Economics. 196:261-268.

Battini D., Delorme X., Dolgui A., Sgarbossa F., 2015. Assembly line balancing with ergonomics paradigms: two alternative methods. 15th IFAC Symposium on Information Control Problems in Manufacturing, pp. 586–91. May 11-13. Ottawa, ON, Canada.

Battini D., Faccio M., Persona A., Sgarbossa F., 2011. New methodological framework to improve productivity and ergonomics in assembly system design. International Journal of Industrial Ergonomics. 41:30–42.

Bortolini M., Faccio M., Gamberi M., Pilati F., 2018. Motion Analysis System (MAS) for production and ergonomics assessment in the manufacturing processes. Comput. Ind. Eng.

Botti L, Mora C, Regattieri A. 2017a. Integrating ergonomics and lean manufacturing principles in a hybrid assembly line. Computers & Industrial Engineering. 111:481–491.

Botti L., Mora C., Regattieri A., 2017b. Application of a mathematical model for ergonomics in lean manufacturing. Data in Brief. 14:360–365.

Canadian Centre for Occupational Health and Safety. 2017. What are work-related musculoskeletal disorders (WMSDs). Available from: www.ccohs.ca/oshanswers/diseases/rmirsi.html [accessed 15 June 2019].

Colombini D., Grieco A., Occhipinti E., 2002. Risk Assessment and Management of Repetitive Movements and Exertions of Upper Limbs : Job Analysis, Ocra Risk Indices, Prevention Strategies, and Design Principles. Amsterdam ; Boston : Elsevier, ©2002.

Dotoli M., Epicoco N., Falagario M., Costantino N., 2015. An integrated approach for warehouse analysis and optimization: A case study. Computers in Industry. 70:5-69.

Golabchi A., Guo X., Liu M., Han S., Lee S., AbouRizk S., 2018. An integrated ergonomics framework for evaluation and design of construction operations. Automation in Construction. 95:72–85.

Golabchi A., Han S., Fayek AR., 2016. A fuzzy logic approach to posture-based ergonomic analysis for field observation and assessment of construction manual operations. Canadian Journal of Civil Engineering. 43(4):294–303.

Golabchi A., Han S., Seo J., Han S., Lee S., Al-Hussein M., 2015. An Automated Biomechanical Simulation Approach to Ergonomic Job Analysis for Workplace Design. Journal of Construction Engineering and Management. 141(8):1–12.

Hignett S., McAtamney L., 2000. Rapid Entire Body Assessment (REBA). Applied Ergonomics. 31(2):201-205

Hochdörffer J., Hedler M., Lanza G., 2018. Staff scheduling in job rotation environments considering ergonomic aspects and preservation of qualifications. Journal of Manufacturing Systems. 46:103–14.

Ikuma LH., Nahmens I., James J., 2011. Use of Safety and Lean Integrated Kaizen to Improve Performance in Modular Homebuilding. Journal of Construction Engineering and Management. 137(7):551-560.

Inyang N., Han S., Al-Hussein M., El-Rich M., 2012. A VR model of ergonomics and productivity assessment in panelized construction production line. Construction Research Congress 2012: Construction Challenges a Flat World, pp. 1084–1093. May 21-23. Lafayette, IN, USA.

Jia Z., Lu X, Wang W., Jia D., 2013. Design and Implementation of a Lean Facility Layout System of a Production Line. International Journal of Industrial Engineering. 20(7-8):502-514.

Karhu O., Kansi P., Kuorinka I., 1977. Correcting working postures in industry: A practical method for analysis. Applied Ergonoics. 8(4):199–201.

Li G., Buckle P., 1999. Current techniques for assessing physical exposure to work-related musculoskeletal risks, with emphasis on posture-based methods. Ergonomics. 42(5):674–695.

Li H., Lu M., Hsu S-C., Gray M., Huang T., 2015. Proactive behavior-based safety management for construction safety improvement. Safety Science. 75:107–117.

Li X., 2017. Ergonomic Risk Assessment in Construction Manufacturing Facilities. Thesis (PhD). University of Alberta.
Li X., Gül M., Al-Hussein M., 2019. An improved physical demand analysis framework based on ergonomic risk assessment tools for the manufacturing industry. International Journal of Industrial Ergonomics. 70:58–69.
Li X., Han S., Gül M., Al-Hussein M., El-Rich M., 2017a. 3D visualization-based ergonomic risk assessment and work modification framework and its validation for a lifting task. Journal of Construction Engineering and Management. 144(1):4017093.
Li X., Komeili A., Gül M., El-Rich M., 2017b. A framework for evaluating muscle activity during repetitive manual material handling in construction manufacturing. Automation in Construction. 79:39–48.
McAtamney L., Nigel Corlett E., 1993. RULA: a survey method for the investigation of work-related upper limb disorders. Applied Ergonomics. 24(2):91–99.
Mossa G., Boenzi F., Digiesi S., Mummolo G., Romano VA., 2016. Productivity and ergonomic risk in human based production systems: A job-rotation scheduling model. International Journal of Production Economics. 171(Part 4):471–77.
Stanford University, 2012. OpenSim User's Guide.
Public Services Health & Safety Association (PSHSA). 2010. Repetitive work: Could you please repeat that … again and again and again? Available from: www.pshsa.ca/wp-content/uploads/2013/01/RepetitiveWorkInjury.pdf [accessed 21 April 2019].
Rajabalipour Cheshmehgaz H., Haron H., Kazemipour F., Desa MI., 2012. Accumulated risk of body postures in assembly line balancing problem and modeling through a multi-criteria fuzzy-genetic algorithm. Computers & Industrial Engineering. 63:503–512.
Ritter C., Li X., Al-Hussein M., 2016. Production monitoring and process improvement for floor panel manufacturing. Proceedings, Modular and Offsite Construction Summit, pp. 75–82. September 2—October 1. Edmonton, AB, Canada.
The University of Michigan Center for Ergonomics, 2017. 3D Static Strength Prediction Program™ Version 7.0.0: User's Manual.
Yu H., Al-Hussein H., Al-Jibouri S., Telyas A., 2013. Lean Transformation in a Modular Building Company: A Case for Implementation. Journal of Management in Engineering. 29(1):103-111.
Xu Z., Ko J., Cochran DJ., Jung M-C., 2012. Design of assembly lines with the concurrent consideration of productivity and upper extremity musculoskeletal disorders using linear models. Computers & Industrial Engineering. 62:431–41.

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