Designing Workplace Robots: A Game for Automation and Augmentation Strategies in Construction*

Sihui Wu, Kim Norgaard Helmersen, Li Chen, and Gudela Grote

***Abstract*— Robotics have emerged with great opportunities for the construction sector. To fully realize the technological, social, and economic benefits of construction robots, it is essential to assess their implications for worker well-being in the early design. This paper introduces *BuildWork*, an educational game developed for robot designers and implementers to enhance their work design considerations and support decision-making regarding automation and augmentation strategies. The game invites players to complete a simulated building project, while prompting them to consider work design criteria, worker competence and motivation, as well as robot type and autonomy. *BuildWork* will be piloted with industry practitioners and evaluated based on their perceived learning. The study contributes to inter- and transdisciplinary research and offers a practical tool for promoting impact-aware mindsets. It highlights the central premise that improving worker satisfaction can enhance performance outcomes.**

***Keywords*— Robotics and Automation in Construction; Design and Human Factors; Human-Robot Interaction; Human-Centered Automation.**

I. Introduction

In addition to gains in efficiency and accuracy, firms are increasingly motivated to adopt robotics due to their potential to enhance worker safety and support workforce augmentation. However, the consideration of such social and organizational implications during robot design is hindered by a lack of appropriate knowledge and methodological frameworks. As robots become more ubiquitous in the workplace, it is essential to understand how construction work may be transformed accordingly.

One of the theories that analyses work environment is socio-technical systems theory. This theory suggests that the joint optimization of the social and technical components of a complex system leads to the most effective performance [1]. In this context, careful design of both the robotic system and the work system is essential to minimize risks and leverage benefits associated with workplace robots. This requires continuous assessment of design strategies, in other words, whether robots should fully replace human labor (i.e., automation), or instead augment human capabilities in performing a task (i.e., augmentation). For instance, complementary system design methods for function allocation look at how tasks may be optimally distributed between humans and robots to improve the effectiveness and safety of automated systems [2].

Construction workers are the primary workforce on site that have a significant impact on project productivity and the quality of construction work [3]. Previous research indicates that employees are often coerced to accept robotic technologies, thereby causing psychological harm [4]. One recent study found that the decision to implement robots in warehouse jobsites was mostly driven by economic and technological factors instead of job quality considerations [5]. Such studies highlight the importance to design good jobs alongside developing good technologies, which requires the consideration of work design principles [6]. Characteristics of "good jobs" are defined by working conditions that promote positive outcomes for employees, which besides effective performance also concern well-being and positive attitudes such as job satisfaction [7].

More specifically, prospective work design considers effective design of work characteristics already in the early phases of technology design and deployment [8]. Practitioners involved in these phases, such as a navigation engineer in a robotics company or an innovation manager in a construction company, play a critical role, as their decisions significantly influence technologies' impact on work and workers. In this context, we highlight the need for a tool that supports these stakeholders in applying work design principles and integrating human and organizational requirements into innovation processes of technology.

We therefore propose the use of a serious game as an educational tool. Serious games, referring to "games designed for a primary purpose other than pure entertainment," have been shown to promote learning by enabling users to gain practical experience within a simulated environment [9]. This paper presents the theoretical foundation and development of *BuildWork*, a game designed to increase awareness among robot designers and implementers of the social implications associated with construction robotics, while supporting their decision-making in automation and augmentation strategies. We argue that higher job motivation and satisfaction, in turn, can lead to improved worker performance, thereby increasing overall project productivity and quality.

II. Theoretical Departure

Designing and implementing construction robots requires making important decisions around the work, workers, and robots. In the following sections we elaborate on our theoretical departure in these three components for the game development.

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A. Work design criteria

Construction robots can positively or negatively affect work characteristics including autonomy/control, skill variety and use, job feedback, social and relational factors, and tolerable demands [6]. *Job autonomy and control* is one of the most important characteristics of work. The first type of job autonomy involves having control over how work processes are carried out. While decision-making tasks are increasingly supported by algorithms and data-driven technologies—such as those based on big data and machine learning for quality improvement or risk mitigation [10]—there is also a risk associated with automation. Specifically, when technology is designed to maximize automation, it may leave humans "out of the loop", thereby reducing their sense of autonomy [11].

The second dimension of job autonomy concerns the opportunity to choose the timing and methods of work. Information and communication technologies facilitate flexible work arrangements in terms of time and location, thereby enabling improved work-life balance [12]. However, these potential benefits are not always realized, as co-workers' expectations for constant connectivity may reduce one's perceived control over the actual flexibility, thereby diminishing the intended autonomy [13].

Skill variety and use refer to the extent to which work involves diverse activities and enables the application of one's abilities, thereby contributing to meaningfulness of the work. The integration of robots to perform tasks that are "dull, dirty, or dangerous" can enhance skill variety by freeing workers to engage in more complex and value-added activities [14]. However, technological interventions can also have the opposite effect. For example, automation may fragment work into repetitive micro-tasks, reducing its meaning and interest [15].

Job feedback refers to the provision of "knowledge of results" which in turn increases motivation and ensures effective performance [16]. Technological tools, such as wearables and digital devices, can enhance feedback by offering real-time performance data, thereby supporting individual learning and development. But these benefits may be offset by over-reliance on technology causing skill loss over time. For example, the use of robotic systems in healthcare has been shown to reduce opportunities for trainee surgeons to engage in complex procedures, which may impair their experiential learning [17].

Social and relational factors, such as social contact, social support, and interdependence, are critical determinants of employees' satisfaction, commitment, and emotions at work. Technologies can facilitate teamwork and strengthen interpersonal connections, particularly among distributed or remote teams [18]. However, technology can also disrupt relational dynamics. For instance, introducing robots in collaborative settings may alter physical coordination among workers, potentially weakening their social interaction [19].

Tolerable job demands relate to the physical, psychological, social, or organizational aspects of work, when excessive, may contribute to overload. Robotics can alleviate certain physical demands by automating heavy manual tasks, thereby reducing physical strain on workers [20]. However, such technologies may also introduce unintended negative effects. Specifically, the use of sensors and electronic monitoring systems—often implemented to enhance efficiency—can increase cognitive demands, potentially leading to new forms of stress for employees [21].

B. Worker competence and motivation

The use of robotics is reshaping the skill requirements for human workers who interact with these technologies. The construction sector is characterized by a highly fragmentated value chain, and heterogeneous workforce, ranging from low-skill labor to highly specialized labor. On the other hand, effective engagement with robotic technologies requires workers to develop a wide range of digital competencies, from basic and intermediate skills (e.g., internet use, data analytics) to advanced, task-specific skills (e.g., programming, robot operation) [22].

Construction robotics is transforming both the nature of work and the work environment, potentially affecting workers' motivation in either positive or negative ways. Increased motivation has been associated with higher productivity and improved job retention. While extrinsic incentives such as salary can enhance performance, specific features of job may also enhance motivation. These job characteristics include autonomy, meaningful work, and opportunities for growth, which are essential for fostering intrinsic motivation and job satisfaction [23]. In addition, variables such as coworker relations and human-technology interactions are determinants associated with motivational outcome and work behavior [24].

C. Robot type and autonomy level

A central consideration in robot design concerns the allocation of functions between humans and robots, specifically, which subtasks should be automated and to what extent. This design strategy is critical, as robots may not only substitute human labor but also transform work processes and introduce new requirements for coordination. In the construction sector, robotic systems can be categorized based on two primary strategies: augmentation, which refers to enhancing human performance, and full automation, which entails replacing human involvement entirely. These strategies are linked to the levels of robot autonomy, which range from low to high and correspond to the degree of human control. Autonomy can be further classified according to four task types: information acquisition, information analysis, decision selection and action implementation [25].

In augmentation scenarios, human workers transition from performing physical tasks to cognitive roles, with robots providing assistance. For example, the brick-laying system SAM [26] and the material-lifting robot MULE [27] augment human strength, while humans retain overall control. In contrast, fully automated systems are designed to operate without human interaction. Examples include robotic concrete printing COBOD [28] and floor layout robots FieldPrinter [29] which perform tasks autonomously, whereas humans intervene in safety-critical situations.

III. Development of The Game

The development of *BuildWork* followed a multi-stage, iterative process. Initially, focus groups were conducted with key stakeholders, including innovation managers from construction companies, for gaining insights into their practices related to automation. Based on the findings from this ideation phase, a paper prototype of the game was created using simple physical components, including an A3-sized game board and printed cards. Then, to evaluate and refine the game design, the prototype was tested with diverse participants. Feedback from these sessions informed revisions to both the game mechanics and the user interface. Finally, the digital version of the game was implemented on the Candli platform. Game experts were involved throughout the process, from initial conceptualization to technical programming of the digital version.

The main interface of *BuildWork* is depicted in Figure 1. Players are tasked with completing a building project divided into three subtasks: floors, walls, and finishing. The objective is to complete the tasks within budget and on time while keeping the happiness level of the employees as high as possible. Before starting the game, players are guided through a slider tutorial to familiarize themselves with the rules.

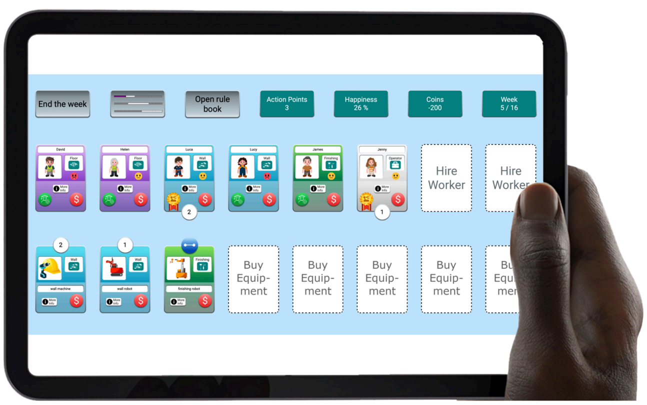

Figure 1. Main interface design of *BuildWork*.

Throughout the gameplay, players make decisions regarding the hiring and relocation of workers, as well as the acquisition or sale of robots to advance the building process. Additionally, players can team up multiple workers or train workers as operators and link them to equipment. For effective gameplay, players are required to make employee and technology selections based on their understanding of workers' skills and preferences, as well as the costs and automation levels of the available equipment.

Players' work design considerations are embedded in the game and translated into job satisfaction in terms of the employees' happiness points, which in turn affect individual productivity. This game dynamic is based on the underlying assumption that happy workers are more motivated, leading to more effective performance outcomes. It prompts players to actively monitor and improve employee happiness throughout the gameplay. As shown below, overall productivity ($P_{overall}$) is the sum of individual productivity from specialists (n) and equipment (m) linked with operators. Individual productivity ($P_{individual}$) equals a baseline of 50 plus changes in productivity ($\triangle P$) driven by whether, and how, worker preferences are satisfied.

$$P_{overall} = \sum\nolimits_0^n P_{specialist} + \sum\nolimits_0^m \left(P_{operator\_linked} + P_{equipment\_linked} \right)$$

$$P_{ind.} = 50 + \triangle P^{*} \begin{cases} \text{dislike/like}^{**} \begin{cases} \text{linked} + 10 \\ \text{not linked} \begin{cases} \text{teamed} - 10 \\ \text{not teamed} \pm 0 \end{cases} \end{cases} \\ \text{like/dislike}^{**} \begin{cases} \text{teamed} + 10 \\ \text{not teamed} \begin{cases} \text{linked} - 10 \\ \text{not linked} \pm 0 \end{cases} \end{cases} \\ \text{neutral/neutral}^{**} \pm 0 \end{cases}$$

*operation stops when $P_{ind.} \geq 80$ and ≤ 30

**preferences in working with: others/equipments

The game introduces further complexity through unexpected events, such as "robot breakdowns" or "employee sickness," which can disrupt the workflow. As the game progresses and upon completion of the game, players receive summaries of their performance based on three primary indicators: "schedule," measured by the number of days required to complete the project; "budget," indicated by the remaining coins; and "employees," represented by the average happiness level (%) of all workers.

IV. Discussion and Future Research

We presented the *BuildWork* game—a novel learning tool for designing workplace robots that integrates job satisfaction concepts alongside automation and augmentation strategies. This research contributes to the literature by bringing together fragmented perspectives from technology innovation, work design, human factors, and human-robot interaction. Additionally, the study bridges academic disciplines with industry practices, thereby achieving inter- and transdisciplinary outcomes [30]. This approach aims to foster more holistic and impact-aware mindsets among practitioners involved in the development, design, procurement, and implementation of new technologies.

One theoretical contribution of the study lies in applying a serious game for educational purposes. *BuildWork* engages participants in complex decision-making processes and enables them to observe and reflect on the consequences of their action, particularly regarding employee well-being. This learning process is illustrated in Figure 2, which shows how decisions by players regarding employee and technology selection were operationalized into three qualitative game outcomes: good (green, thumbs up), moderate (yellow, thumbs sideways), and poor (red, thumbs down). This gives players feedback on their choices and potentially translates their game experience into knowledge. As a next step, the game will be piloted with industry practitioners and evaluated based on participants' perceived learning.

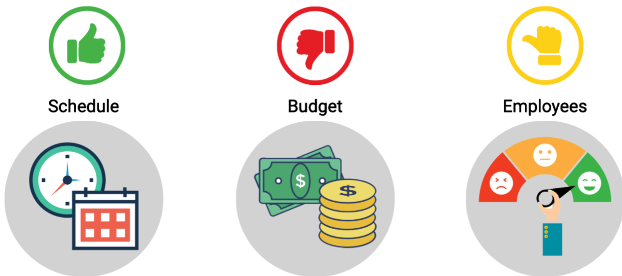

Figure 2. Example of performance evaluation at the end of the game.

An additional contribution of *BuildWork* is its practical opportunities. Its flexible design enables the exploration of future scenarios with a broader set of variables, including emerging technologies (e.g., artificial intelligence systems), or other human factors (e.g., learning curves of trainees). For training construction managers, the game has the potential to cultivate value-driven management competencies, further translating into behaviors such as making socially informed decisions when acquiring technologies and selecting personnel for construction projects in real-world settings.

Moving forward, *BuildWork* will be continuously and iteratively refined based on player feedback from pilot studies. All participants are invited to complete an online questionnaire evaluating their experience, such as perceived strengths and weaknesses of the game. For future research, the game may be integrated into intervention studies that collect data through reflection-on-action or experiments to empirically examine and validate its influence on industry practitioners' mindsets and decision-making processes.

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References

[1] P. Waterson, M. M. Robertson, N. J. Cooke, L. Militello, E. Roth, and N. A. Stanton, "Defining the methodological challenges and opportunities for an effective science of sociotechnical systems and safety," *Ergonomics*, vol. 58, no. 4, pp. 565–599, 2015.

[2] G. Grote, C. Ryser, T. Wäfler, A. Windischer, and S. Weik, "KOMPASS: A method for complementary function allocation in automated work systems," *Int. J. Human-Computer Studies*, vol. 52, no. 2, pp. 267–287, 2000.

[3] S. Johari and K. N. Jha, "Impact of work motivation on construction labor productivity," *J. Manage. Eng.*, vol. 36, no. 5, 2020.

[4] O. Bendel, "Co-robots from an ethical perspective," in *Proc. Business Information Systems and Technology 4.0*, pp. 275–288, 2018.

[5] H. A. Berkers, S. Rispens, and P. M. Le Blanc, "The role of robotization in work design: A comparative case study among logistic warehouses," *Int. J. Human Resource Manage.*, vol. 34, no. 9, pp. 1852–1875, 2022.

[6] S. K. Parker and G. Grote, "Automation, algorithms, and beyond: Why work design matters more than ever in a digital world," *Appl. Psychol.*, vol. 71, no. 4, pp. 1171–1204, 2022.

[7] F. Green, *Demanding Work: The Paradox of Job Quality in the Affluent Economy*. Princeton, NJ: Princeton Univ. Press, 2006.

[8] A. Kahlert and G. Grote, "'Why should I care?': Understanding technology developers' design mindsets in relation to prospective work design," *Eur. J. Work Organ. Psychol.*, vol. 33, no. 2, pp. 230–244, 2024.

[9] D. Rumeser and M. Emsley, "Can serious games improve project management decision making under complexity?," *Proj. Manage. J.*, vol. 50, no. 1, pp. 23–39, 2018.

[10] H. Chen and K. Ying, "Artificial intelligence in the construction industry: Main development trajectories and future outlook," *Appl. Sci.*, vol. 12, no. 12, Art. no. 5832, 2022.

[11] C. E. Billings, "Human-centered aircraft automation: A concept and guidelines," NASA, United States, 1991. [Online]. Available: https://ntrs.nasa.gov/search.jsp?R=19910022821

[12] T. Johns and L. Gratton, "The third wave of virtual work," *Harvard Bus. Rev.*, vol. 91, no. 1, pp. 66–73, 2013.

[13] P. M. Leonardi, J. W. Treem, and M. H. Jackson, "The connectivity paradox: Using technology to both decrease and increase perceptions of distance in distributed work arrangements," *J. Appl. Commun. Res.*, vol. 38, no. 1, pp. 85–105, 2010.

[14] S. M. Walsh and M. S. Strano, *Robotic Systems and Autonomous Platforms: Advances in Materials and Manufacturing*. Duxford:Woodhead Publishing, 2018.

[15] V. Lehdonvirta and M. Ernkvist, *Knowledge Map of the Virtual Economy: Converting the Virtual Economy into Development Potential*. World Bank Group, 2011.

[16] D. Banta, "What is technology assessment?," *Int. J. Technol. Assess. Health Care*, vol. 25, no. S1, pp. 7–9, 2009.

[17] M. Beane and W. J. Orlikowski, "What difference does a robot make? The material enactment of distributed coordination," *Organ. Sci.*, vol. 26, no. 6, pp. 1553–1573, 2015.

[18] K. C. Kellogg, W. J. Orlikowski, and J. Yates, "Life in the trading zone: Structuring coordination across boundaries in postbureaucratic organizations," *Organ. Sci.*, vol. 17, no. 1, pp. 22–44, 2006.

[19] C. D. Cramton and S. S. Webber, "Relationships among geographic dispersion, team processes, and effectiveness in software development work teams," *J. Bus. Res.*, vol. 58, no. 6, pp. 758–765, 2005.

[20] M. Barrett, E. Oborn, W. J. Orlikowski, and J. Yates, "Reconfiguring boundary relations: Robotic innovations in pharmacy work," *Organ. Sci.*, vol. 23, no. 5, pp. 1448–1466, 2012.

[21] C. Shepherd, "Constructing enterprise resource planning: A thoroughgoing interpretivist perspective on technological change," *J. Occup. Organ. Psychol.*, vol. 79, no. 3, pp. 357–376, 2006.

[22] K. Banga and D. W. te Velde, "Skill needs for the future," *Pathways for Prosperity Commission Background Paper Series*, no. 10, Oxford, U.K., 2018.

[23] R. Kanfer, M. Frese, and R. E. Johnson, "Motivation related to work: A century of progress," *J. Appl. Psychol.*, vol. 102, no. 3, pp. 338–355, 2017.

[24] R. D. Meyer, R. S. Dalal, and R. Hermida, "A review and synthesis of situational strength in the organizational sciences," *J. Manage.*, vol. 36, pp. 121–140, 2010.

[25] R. Parasuraman, T. Sheridan, and C. Wickens, "A model for types and levels of human interaction with automation," *IEEE Trans. Syst., Man, Cybern. A*, vol. 30, no. 3, pp. 286–297, 2000.

[26] Construction Robotics, "Semi-automated mason - Sam," 2016. [Online]. Available: https://www.construction-robotics.com/sam-2/

[27] Construction Robotics, "Smart Lifting for Construction and Masonry - Mule," 2016. [Online]. Available: https://www.construction-robotics.com/mule-3/

[28] Cobod, "Projects," 2018. [Online]. Available: https://cobod.com/projects-cobod/

[29] Dusty Robotics, "FieldPrinter," 2018. [Online]. Available: https://www.dustyrobotics.com/

[30] R. W. Scholz and G. Steiner, "The real type and ideal type of transdisciplinary processes: Part II—what constraints and obstacles do we meet in practice?," *Sustain. Sci.*, vol. 10, no. 4, pp. 653–671, 2015.