BuildWork: A Serious Game for Impact-Aware Automation in Construction

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Introduction

As digitalization advances, construction firms increasingly adopt robotics to address productivity, safety, and labor shortage issues (ABB, 2021; Bock, 2015). Robotics in construction originated in 1970s Japan with early prefabrication and automated sites (Bock, 2006). Since the 2010s, Industry 4.0 technologies have enabled advanced sensing and control (Oesterreich & Teuteberg, 2016), supporting applications such as rebar assembly and excavation (Dörfler et al., 2019; Johns et al., 2020) and commercial systems including Canvas and Jaibot (Canvas, 2017; Hilti, 2020). Construction robots increasingly operate as human-robot interaction systems within unstructured, dynamic site environments (Hall et al., 2025). Research further shows that successful construction robot adoption depends on stakeholders' perceptions and intentions, not only on technical performance. Walzer et al. (2022) demonstrate that workers and managers interpret construction robots differently in terms of safety, control, and social presence, while Wu et al. (2024) show that intentions to use construction robots arise from specific configurations of technological, organizational, and individual conditions.

Hence, deploying robots in construction constitutes a socio-technical transformation that requires considerations of technological impacts on workers and their work. This points to the importance of designing good jobs alongside good technologies through work design principles (Parker & Grote, 2022). Good jobs are characterized by working conditions that support performance, well-being, and positive work attitudes such as job satisfaction (Green, 2006). For effective robot implementation in construction, a prospective work design approach is therefore necessary because it addresses technology's impacts early in the design and deployment process (Kahlert & Grote, 2024), for example by integrating tangible user interfaces into construction robots that support creative learning and meaningful engagement with robotic capabilities (Skevaki et al., 2025). Construction workers remain central to on-site productivity and quality outcomes (Johari & Jha, 2020). However, research shows that they are often coerced into accepting robotic technologies, resulting in psychological harm (Bendel, 2018), while adoption decisions are primarily driven by economic and technological considerations rather than job quality (Berkers et al., 2022). Together, these findings highlight the need for methodologies and tools that support construction managers in making automation decisions informed by work design thinking.

Various intervention formats have been proposed to support such reflective decision-making, including guidelines, participatory workshops, and action research approaches (Bradbury, 2015; Van de Ven, 2007). Among these, serious games are one important and innovative example of inter- and transdisciplinary methods that integrate research, education, and practice (Scholz & Steiner, 2015). Serious games are games not primarily intended for entertainment but designed with explicit educational or research purposes (Abt, 1987). In research, they function as simplified models of real-world systems, enabling the study of interactions between people, organizations, and environments in complex socio-technical contexts (Klabbers, 2006; Grogan & Meijer, 2017). They provide an engaging and safe experimental environment in which participants can explore decisions without real-world consequences (Washburn, 2003; Wang et al., 2019). Existing construction serious games have largely targeted production and project management outcomes. Tommelein et al.'s (1999) Parade Game demonstrates how work-flow variability propagates across trades and degrades performance, and Rybkowski et al. (2016) used lean simulations to teach Target Value Design and collaborative cost management. More recent, digitally enabled games extend these principles to digital fabrication and online delivery (Ng & Hall, 2021). Across these examples, the unit of analysis remains cost, time, and production flow, and the worker is treated as a productivity input rather than as a stakeholder whose well-being and job quality are themselves design outcomes. In this paper, we report the development and testing of *BuildWork*, a serious game that addresses this gap by making work design considerations explicit.

Research Methods

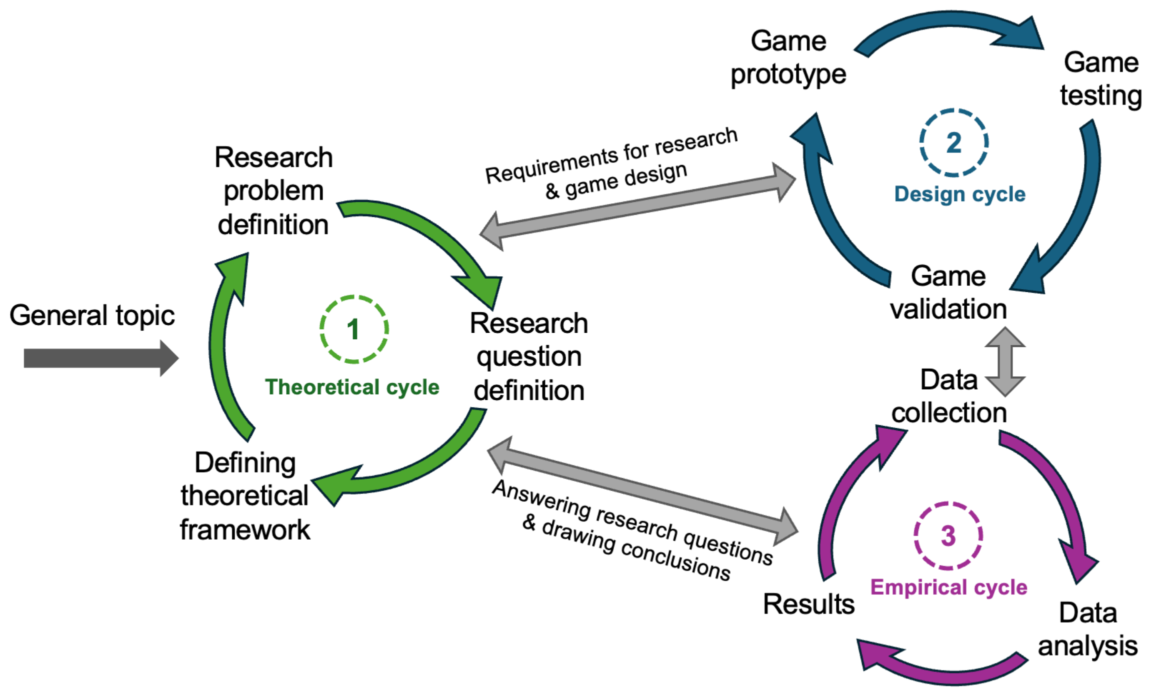

Figure 1. Overview of the game research by design process (based on Freese & Bekebrede, 2025).

Inspired by Freese and Bekebrede (2025), we structured our research process based on the Game Research by Design approach, which is conceptualized as an iterative process across three interrelated cycles: theoretical, design, and empirical (see Figure 1). The theoretical cycle derives research questions and requirements from existing theory and system analysis. The design cycle translates these requirements into a valid research game and experimental setup, balancing realism, playability, and data needs. The empirical cycle uses gameplay to collect and analyze mixed-methods data, linking observed behavior back to theory and refining both research questions and game design.

Theoretical cycle

The game logic builds on four theoretical foundations. First, socio-technical systems theory emphasizes the joint design of robotic systems and work systems as a prerequisite for effective performance (Clegg, 2000; Waterson et al., 2015). Second, work design principles highlight the importance of autonomy and control, skill variety and use, job feedback, social and relational factors, and tolerable demands in shaping job quality and work outcomes (Parker & Grote, 2022). Third, theories of worker competence and motivation address how construction robotics transforms skill requirements across a heterogeneous workforce (Banga & te Velde, 2018), linking productivity to meaningful work and job satisfaction (Kanfer et al., 2017). Finally, human-robot function allocation theories emphasize how different levels of robot autonomy redistribute cognitive and physical work, influencing managerial choices that distinguish between augmentation and full automation strategies in construction settings (Parasuraman et al., 2000).

Drawing on these perspectives, the game is designed to raise managers' awareness of the socio-technical implications of automation decisions in construction. Through serious gaming, our research investigates managers' actions and priorities when implementing automation on construction sites, the consequences of these decisions, and the underlying rationales that shape their choices and learning processes.

Design cycle

The development of *BuildWork* followed a participatory and iterative design process. The process began with focus groups involving key stakeholders, including innovation managers from construction companies, to elicit insights into current automation practices and managerial decision-making. Based on this ideation phase, an initial paper prototype was developed using simple physical components, including an A3-sized game board and printed cards. As illustrated by Figure 2, this prototype was subsequently tested with diverse participant groups to evaluate usability, game logic, and learning potential. Feedback from these sessions informed iterative refinements to the game mechanics and user interface. The final online version of *BuildWork* was programmed on the Candli platform (Enlightware GmbH, 2025), with continuous input from game design experts throughout development.

In BuildWork, players manage a construction project comprising three subtasks (floors, walls, and finishing) with the objective of completing the project on time and within budget while maintaining high employee happiness. Gameplay involves decisions related to hiring, relocating, training workers, and acquiring or selling robotic equipment. These decisions require players to consider workers' skills and preferences alongside the costs and automation levels of available technologies. Work design considerations are embedded in the game through employee happiness points, which influence productivity, reflecting the assumption that motivation enhances performance. The game further incorporates uncertainty through unexpected events, such as robot breakdowns or employee sickness. At the end of the game, performance feedback is provided through indicators of schedule, budget, and employee happiness, enabling players to reflect on the consequences of their decisions and translate gameplay experience into learning outcomes.

Figure 2. The paper prototype of *BuildWork* was designed through an iterative, participatory process.

Each of these mechanics maps onto one of the four theoretical foundations described above. The simultaneous management of workers and robotic equipment across the three subtasks reflects the socio-technical principle of jointly designing work and technical systems. Work design principles of skill variety, skill use, and autonomy are embodied in decisions to hire, relocate, and train workers, while the employee happiness points represent job quality and its motivational link to productivity. Finally, the choice to acquire or sell equipment of differing automation levels reflects human-robot function allocation, requiring players to weigh augmentation against full automation as a redistribution of cognitive and physical work.

Empirical cycle

The Research Game by Design Approach enables rich mixed-methods data collection, combining behavioral, quantitative, and qualitative insights that are difficult to capture through traditional methods, making them particularly suitable for socio-technical systems research (Lukosch et al., 2015; Lieberoth & Roepstorff, 2015). The empirical cycle consisted of two complementary phases of data collection and analysis to address both behavioral outcomes and learning processes. First, a quantitative study examined managerial decision-making by analyzing players' actions and their consequences in the game. Participants included practitioners and students involved in robot design and implementation across robotics, mechanical engineering, civil engineering, and construction management. Recruitment followed a purposive sampling strategy with snowballing (Parker et al., 2019), initiated through project partners and professional networks. In total, 132 complete game sessions were recorded, each capturing players' choices such as hiring workers, acquiring equipment, or progressing the construction timeline. An example of the in-game status is shown in Figure 3. These actions were logged with predefined codes and variables, providing a detailed picture of decision-making dynamics. Descriptive and relational analyses (Field, 2018; Hair et al., 2019) were conducted to identify patterns linking automation and work design decisions to project performance and employee-related outcomes.

Second, to examine the learning effects of *BuildWork* and uncover the rationale behind managerial choices, a qualitative think-aloud study (Boren & Ramey, 2000; Ericsson & Simon, 1984) was conducted with five managers from a Swiss construction contractor working in lean, BIM, planning, and procurement roles. Participants were recruited through the company's internal network using a poster describing the study, allowing voluntary self-selection (Creswell & Poth, 2018). During gameplay, participants verbalized their thoughts while audio and screen recordings captured their reasoning and interactions. The recordings were transcribed and analyzed using a conversation analysis approach to examine the interactional context between the researcher and the player. In addition, observations of players' behaviors (i.e., in-game reactions and actions) were used to triangulate the findings and strengthen the validity of the results (Someren & Barnard, 1994).

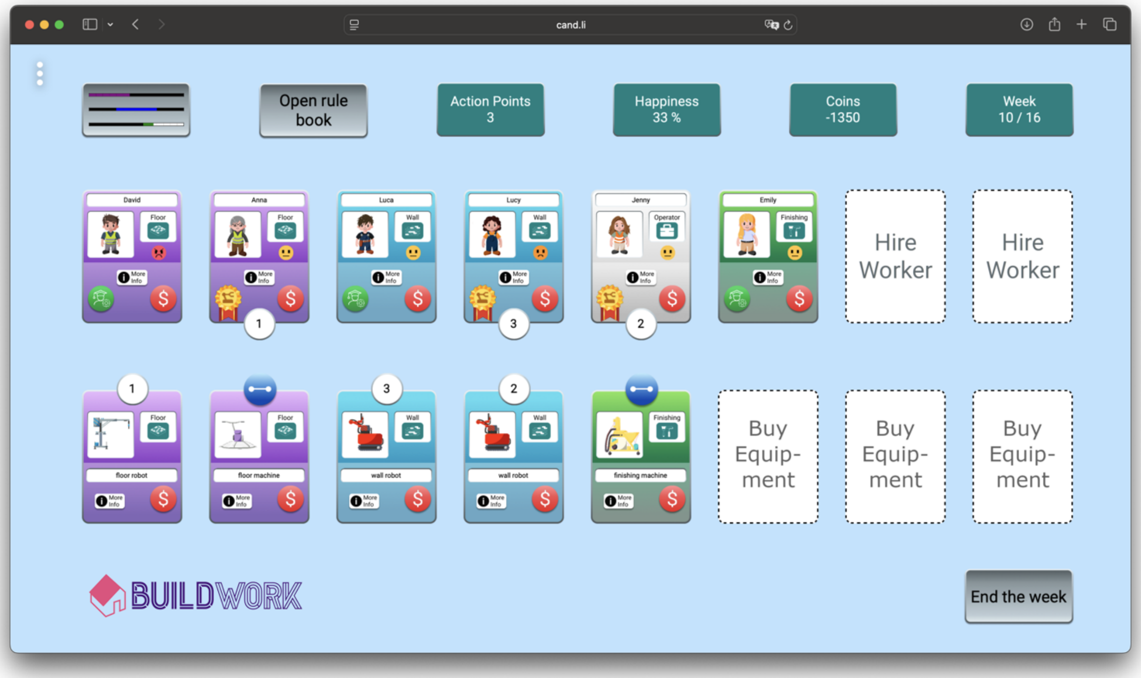

Figure 3. The online version of *BuildWork* was tested in a quantitative and a think-aloud study.

Key Findings

The quantitative data analysis showed distinct tendencies in gameplay choices and their consequences. Most participants (58.3%) prioritized equipment over workers, reflecting a preference for technological investment, while others (34.1%) emphasized engaging human labor to sustain motivation. Only a few (7.6%) distributed their decisions evenly. End-game evaluations reflected the consequences of these different strategies. 66.7% of participants achieved good performance in schedule, but 47% struggled with poor budget control. Worker happiness was generally moderate (65.9%), with a minor share (16.7%) ending with good results. The most frequent outcome combination (19.7%) was high score in scheduling, low score in budgeting, and medium score in happiness. To examine the relationship between human-robot choices and end-game outcomes, our tests revealed that participants' prioritization significantly ($\chi^2 = 81.6$, $p < .001$) affected results. Budget emerged as the primary driver, because participants prioritizing robots outperformed those prioritizing humans. In contrast, the schedule showed weaker links, with participants who prioritize human achieving slightly higher scores than those who prioritize robots. Happiness outcome is not influenced by prioritization at all. These patterns illustrate how BuildWork shows the interplay between project efficiency, financial constraints, and worker well-being, prompting participants to make sense of the broader implications of automation.

Overall, the think-aloud analysis revealed that *BuildWork* supports heterogeneous learning trajectories, distinguishing between reflective, adaptive learners and conservative, rule-following players, thereby highlighting how serious games can surface differences in managerial sensemaking and impact-aware decision-making around automation. The qualitative think-aloud study provided insights into participants' cognitive processes and learning experiences underlying their gameplay behaviors. Across all cases, participants initially engaged in a sensemaking phase, during which they familiarized themselves with the game rules and interface. As gameplay progressed, participants diverged in their strategies and decision styles. Some developed clear priorities, such as maximizing budget performance or maintaining worker happiness, and adapted their strategies after recognizing positive feedback from earlier rounds. Others adopted a more risk-averse approach, maintaining consistent decision patterns across stages to avoid unintended consequences. These gameplay strategies were reflected in participants' learning outcomes. For instance, some participants explicitly recognized the influence of worker satisfaction on productivity and expressed a desire for additional managerial interventions that were not available in the game, indicating a proactive and reflective learning stance. In contrast, other participants adopted a more passive approach, focusing on neutral options without fully engaging with the underlying socio-technical logic of the system.

Implications

The findings reinforce the iterative nature of the Game Research by Design approach, as the development of *BuildWork* required multiple adaptations during prototyping and will continue to evolve based on user feedback. Two key challenges emerged during our research process. First, translating theoretical dimensions from the theoretical cycle into playable game mechanics required careful design to preserve playability without oversimplifying core socio-technical concepts. Second, linking the empirical cycle back to theory raised questions regarding which behavioral and cognitive data best represent the theoretical constructs of interest, as well as how to ensure validity when interpreting data generated in a simulated game environment rather than in real-world settings.

Our results demonstrate that serious games are effective tools for supporting managerial reflection on automation decisions. Participants highlighted the game's simplicity, intuitive interface, and engaging elements as main strengths of the game. From a research perspective, the online format facilitated access to diverse participants, while the modular backend design enabled rapid iteration. Reported limitations included a need for greater realism and richer representations of interdependencies between trades, workers, and robots, suggesting opportunities to increase complexity and expand decision options in future game versions.

Acknowledgement

The authors acknowledge the collaborative support from all involved students, researchers, and practitioners. The game development was supported by game experts from Enlightware GmbH: Lyra Manas, Sonia Horne and Stéphane Magnenat.

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