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LLM-BASED ACTION LEARNING MODEL FOR CONSTRUCTION ROBOTICS: AN INDUSTRY-ACADEMIA CO-DESIGN

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ABSTRACT

The construction industry continues to face challenges in adopting advanced technologies, such as construction robotics, from research to practice. From a lean management perspective, this constitutes wasted scientific effort and limited gain in efficiency and productivity of construction processes. Traditionally, interactive workshops that bring together academic and industry practitioners are commonly used to foster knowledge exchange; however, they often lack structured mechanisms to transform diverse expert insights into actionable solutions to address real-world industry challenges. This paper addresses these limitations by introducing a novel AI-assisted workshop method to prioritize critical problems in construction robotics and develop actionable solution pathways. The approach was implemented during a two-day workshop in Germany, which hosted over 100 leaders in construction robotics from academia and industry. An LLM-supported workflow was used to synthesize expert inputs and the data from the literature to identify key areas with potential for further research. These problems were then prioritized through a democratic live polling process involving all participants. Experts were subsequently divided into breakout groups based on predefined criteria and developed solution approaches using their domain knowledge, which were presented in a final plenary session. This paper reports key lessons learned, including outcomes from expert presentations, throughout this process.

KEYWORDS

Lean construction, collaboration, action learning, large language models (LLMs), construction robotics.

INTRODUCTION

The construction industry has witnessed a rapid growth in construction robotics and automation. However, adoption of recent advancements has been slower compared to other industries. The latest research shows that despite the potential of robotics to improve lean management, both

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in off-site (Gusmao Brissi et al., 2022) and on-site (Hu et al., 2025) construction, the building industry faces many challenges that limit the comprehensive implementation of automation in the construction sector (Feldmann, 2022; Li et al., 2025). Previous research shows that these barriers are not only technical, such as the requirement for high precision, or functional, such as the need for high initial capital, but can also have cultural roots, such as a lack of knowledge about automation applications or people's resistance to change (Alshibani, 2025).

As such, the nature and root causes of these problems are multifaceted and complex; additionally, the corresponding solutions warrant holistic inputs from expert stakeholders from different sectors of the construction robotics value chain. In this context, there is a need to identify these adoption barriers and their corresponding solutions from the perspective of experts. Developing structured and effective stakeholder engagement mechanisms can serve as a means to derive prioritized and actionable solutions from expert knowledge.

On the one hand, participatory and active workshops can offer a versatile platform for various stakeholders, such as policymakers, investors, academic researchers, and industry leaders, to exchange insights, identify barriers, and provide holistic solutions. On the other hand, the emergence of Artificial Intelligence (AI), specifically Large Language Models (LLMs), offers new possibilities to enhance the structure and efficiency of these collaborative media.

This paper presents an LLM-assisted workflow to foster holistic, democratic, and cross-disciplinary representation among various stakeholders, thereby enhancing the practicality, quality, and speed of identified problems and the corresponding actionable solutions. As such, this study aims to address the following research questions:

- What are the actionable solutions to address the adoption challenges in construction robotics from the perspective of experts?
- How can a participatory problem-solving workshop be facilitated using LLMs to minimize information loss and balanced representation in participant inputs?

The proposed framework was adopted during the Construction Robotics Solutions Lab (CoRoSL 2025) workshop, held at OTH Regensburg, Germany, to identify current challenges and provide experts with opportunities to rank-order and define the most significant problems in select areas. These problems were then used to form relevant break-out sessions where experts brainstormed to propose actionable solutions. Finally, the proposed solutions and lessons learnt were identified and shared amongst the participants for the next year's event.

The remainder of the paper is structured as follows: first, a literature review of construction robotics, traditional workshop development, and the implementation of AI/LLMs in analysing participant data is presented. Subsequently, the methodology used during the workshop is explained, and the outcomes are presented in detail in the results section. Finally, the paper concludes with the lessons learned for future organizations, limitations, and future directions for scholars.

BACKGROUND

CONSTRUCTION ROBOTICS AND LEAN THINKING

The emergence of robotics has revolutionized the construction industry. The construction robots have been extensively used for improving the efficiency of tasks such as welding, painting, plastering, and material transportation (Dindorf & Wos, 2024). This improvement can further support the sustainability goals (Rojas et al., 2025). Additionally, studies on Human-Robot Interaction (HRI) and collaborative robotics (cobotics) (Burden et al., 2022; Parascho, 2026) are becoming increasingly popular and can lead to better Lean management due to increasing adaptive processes among humans and robots.

Despite the high potential of construction robotics and the existence of a rich body of academic research in this area (Bock, 2015), there have been barriers to the comprehensive adaptation of these technologies into the building industry (Li et al., 2025). The research has shown that these barriers can be economical, technological, or even cultural (Alshibani, 2025). Furthermore, over the past decades, the International Group for Lean Construction (IGLC) has emphasized that a successful lean implementation is the result of not only technical exercise, but also cultural transformation, which has roots in respect for people, collaborative thinking, and continuous improvement. Several studies that investigate the psychological and physiological aspects of work in Lean environments (Shehab & Hamzeh, 2023) and the effects of worker engagement (Peinado & Costa, 2023), highlight the importance of human experience in the performance outcomes.

The relationship between Lean and digital transformation has also been an area of interest within IGLC. In a study around "Lean Construction 4.0", Hamzeh et al., (2021) highlights the importance of integrating digital technologies with Lean principles, accompanied by human-centered organizational change to have sustainable impacts. In addition, emerging research has focused on the interactions between AI and Lean principles, their challenges, and their promising impacts on supporting human judgment and decision-making (Hatoum & Nassereddine, 2023). In these contexts, there is an opportunity to leverage AI in combination with a structured expert engagement approach to identify the barriers to robotics adoption in the construction industry and their relevant solutions. Workshop settings, which have been proven to facilitate collaborative learning (Murata, 2023), are among the best approaches to bring people from academia and industry together and leverage their insights systemically to categorize the challenges and define actionable solutions for them.

WORKSHOP DEVELOPMENT & STAKEHOLDER MANAGEMENT

Previous research has proved the importance of practical and structured stakeholder engagement activities in prioritizing their performance issues (Vakeva-Baird et al., 2025). In a study by Storvang & Clarke (2014), workshop settings have been proven to be beneficial for better stakeholder involvement and better addressing their concerns. These concerns can effectively support shaping the research directions.

Stakeholder engagement has been widely studied across many disciplines in various forms, such as surveys and workshops. As an example, during a two-day workshop, (Zelt et al., 2019) identified the electricity scenarios up to 2050 for Jordan, Morocco, and Tunisia. In this context, a research team was brought together with local stakeholders. In the agricultural sector, Bourceret et al. (2026) conducted three participatory workshops to reduce pesticide use in farming. And finally, through a systematic review, McGookin et al. (2021) have investigated the extent to which participatory methods, including both qualitative and quantitative methods, have been implemented in energy system modelling and planning. In this context, given the collaborative nature of workshops, the authors also addressed the lack of democratisation in shaping research directions during stakeholder engagement (McGookin et al., 2021).

Finally, despite their widespread use, traditional workshops might suffer from other limitations, such as dominance of discussions by a small group of vocal participants, lack of structured mechanisms to synthesize diverse inputs, and the absence of a systematic process to derive actionable solutions from discussions in these settings (Arakawa & Bader, 2022). Consequently, valuable insights may remain underrepresented or lost, which would lead to inefficiencies in collaborative knowledge generation and consensus building.

AI-SUPPORTED RESEARCH SYNTHESIS

Recently, AI and more specifically LLMs have been occasionally used for analysing participant data from workshops and collaborative sessions across a variety of disciplines. In recent studies,

chatbots and LLMs have been extensively used for workshop design and community engagement (Dortheimer et al., 2024; Yang et al., 2024). As an example, Kozov et al. (2024) implemented a structured and project-based workshop with 130 participants to teach and evaluate their ability to effectively use LLMs while being aware of their limitations. As such, AI and LLMs were found to be effective in participatory workshops for tasks such as ideation, transcript structuring, and meeting analysis (Lim & Perrault, 2024; Lubos et al., 2025; Sato et al., 2024); however, their integration to foster collaborative ideation, particularly in live workshops related to construction informatics, remains a gap in the literature that requires further investigation. Furthermore, there is no methodology in the literature that incorporates the impact of LLMs to guide and facilitate expert discussions, allow participants to prioritize the critical challenges, and eventually investigate clear action plans using their domain knowledge, say within breakout groups. Thus, the present study provides a methodology to integrate multiple LLMs to (i) identify research gaps from participant feedback (as well as relevant literature); (ii) supply a mechanism to internally validate the accuracy of the summarized research gaps; and (iii) offer live polling to expert participants to democratically select the subject area to further develop during the breakout sessions. Subsequently, the action plans are determined by the experts based on the discussions of each breakout group. While the methodology is generic and can be adopted to different settings, here, it was applied to a workshop in construction robotics, the 2nd Construction Robotics Solutions Lab (CoRoSL2025), where leading academics and industry experts were scheduled to participate, present, and showcase their novel solutions.

It is worth noting that the proposed approach builds upon the current body of knowledge by introducing a workshop methodology that combines AI support, consensus building, participatory decision-making, and continuous learning, rather than using AI as a standalone technical tool. Such a human-centered approach can closely contribute to implementing Lean principles by reducing information loss and processing overhead, and strengthening collaborative learning through expert presentations, fair representation of perspectives (respect for diverse opinions), participant feedback, strategic breakout discussions, and annual reviews/revisions. As such, within the Lean Construction 4.0 paradigm, the utility of AI in this study's context can be conceptualized as a tool to improve information flow directly from diverse participant perspectives, processing overhead/waste, decision-making speed, and presenting diverse inputs in a structured manner, all within a value-generating mechanism, that supports data-driven decision-making, optimization of process outcomes and continuous improvement.

METHODOLOGY

WORKSHOP CONTEXT AND STRUCTURE

Following the successful construction robotics workshop in 2023 in Singapore and 2024 in Regensburg, the 3rd CoRoSL conference was held in Regensburg University of Applied Sciences in October 2025, over a span of two days with 110 participants, and leading global experts from diverse sectors of the construction robotics value chain, including investors, policymakers, academics, and industry leaders, providing a rich basis for defining significant problems and proposing actionable solutions. The program started with insightful keynote speeches and presentations from selected participants (both academia and industry) on four key topics. The second day included real-life demonstrations of state-of-the-art construction robotics solutions in the lab, followed by the structured workshop. The program improved considerably in its details and development compared to the CoRoSL in 2024. Examples of these included early program development and planning by the chairs and co-chairs (including two academics from OTH Regensburg, one from Karlsruhe Institute of Technology (KIT), and

two industry-leaders from Kajima), design of collaborative ideas on key topics, and establishment of the live demonstration session, followed by the active workshop. Example of the collaborative planning is shown through the Miro-board below (Figure 1). During this planning, the four key theme areas in construction robotics were identified, namely, (1) Foundations and Ecosystem, (2) Human-Centered Design and Collaboration, (3) Technology and Application, and (4) Implementation and Innovation Pathways.

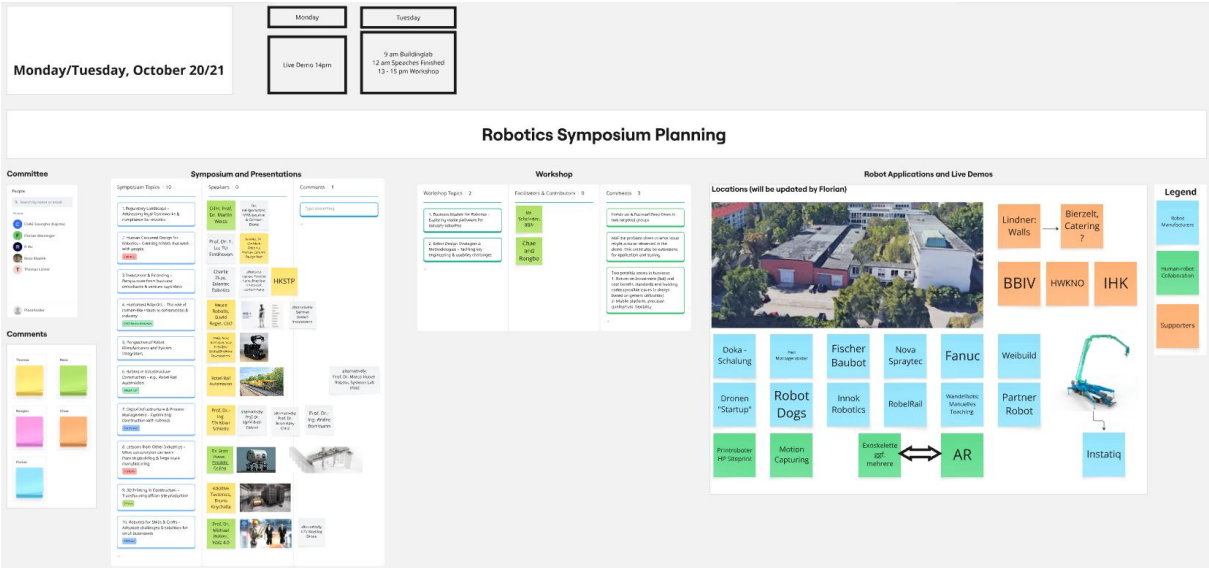

Figure 1: Miro-board example for design and development of the workshop program

The workshop, which took place at the end of the second day, focused on identifying and prioritizing research challenges related to construction robotics across the four thematic sessions. The workshops are designed to foster action learning in construction robotics annually by providing a platform to receive direct feedback from experts with diverse skillsets, experiences, and roles. The diverse background of the participants in the specific field of construction robotics created a rich foundation and a valuable opportunity to receive feedback and insights on current challenges and their relevant actionable measures from not only researchers and professors in academia, but also from industry leaders, project managers, and technology developers. To provide further perspective on the diversity of the participants, the participants entailed around 40 researchers from academia, 17 students, and 55 members from various levels in the industry. A full account of the participant profiles in terms of their roles as well as their regions is provided in Figure 2.

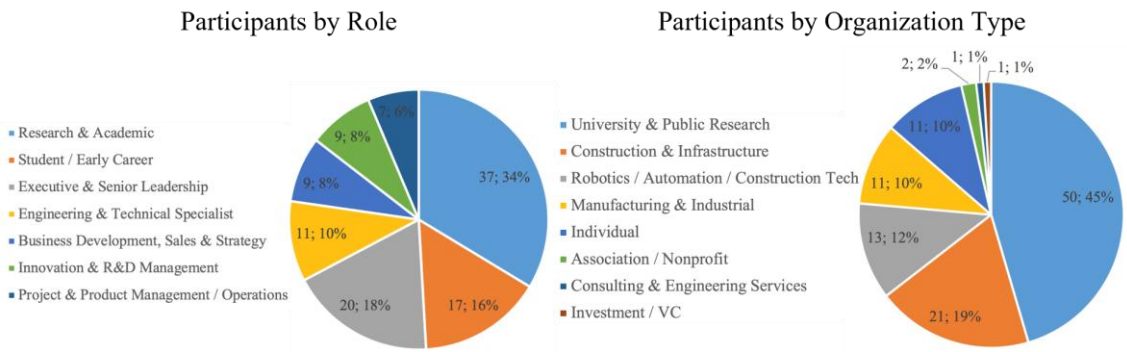

Figure 2: Distribution of participants based on role (left) and organization type (right) visualized through pie chart

PROPOSED AI-SUPPORTED WORKFLOW

The original workshop design aimed to collect expert feedback in real time during the presentation sessions. On the first day, at the end of each presentation, participants were shown a QR code and invited to submit their key insights and potential research directions from their perspectives via a web-based Google form. These textual inputs were automatically collected in an Excel sheet and intended to serve as the primary source for an AI-assisted analysis workflow to define current challenges across four main areas of construction robotics. The proposed pipeline was flexible enough to use a small but representative set of recent academic publications relevant to the session topics, prepared on site in case of unexpected problems with the internet connection or insufficient input data from Google Form submissions.

On the workshop day, three independent LLMs (e.g., Google Gemini 2.5 Pro, 2.0 Flash, and 2.5 Flash) were used to extract candidate research gaps from the selected literature (Google, 2025). These models were selected to ensure diversity in the analysis process and reduce model-specific bias. The outputs were subsequently cross-critiqued to reduce redundancy and hallucination risks, and the top-ranked gaps were retained. This curated corpus was then processed through a topic modelling step using BERTopic (Grootendorst, 2022) pipeline as originally planned due to its high efficiency in performing topic modelling tasks (Egger & Yu, 2022). The resulting topic clusters were interpreted by LLMs into concise research questions to ensure consistency with the intended workflow (Google, 2025). Finally, the top four research questions were presented to the audience using Mentimeter (Mentimeter AB, 2025) at the beginning of the workshop on the second day. The experts were requested to democratically vote and choose which area they would like to discuss more and try to come up with actionable solutions in a breakout group with the other experts.

This methodology was adapted from the authors' previous paper on GAPMiner (currently under review), with modifications to the pipeline and models used. All model versions, prompts, and intermediate artifacts used in this workflow were logged to ensure transparency and reproducibility. Figure 3 illustrates the final methodology implemented during the workshop, including both the planned and fallback workflows.

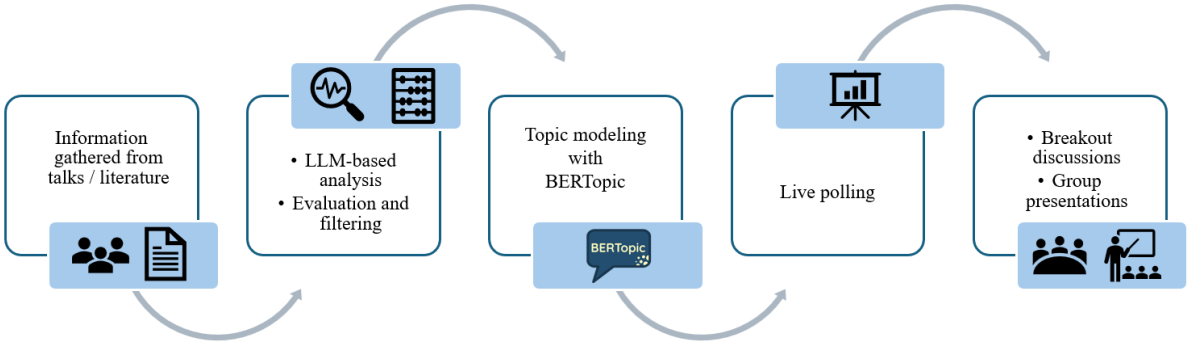

Figure 3: Schematic representation of the developed action learning workshop

GROUP DISCUSSIONS & PRESENTATIONS

After determining the most important point of focus in each category by the experts, the workshop organizers divided the participants into four main groups based on the predefined criteria. Each group was controlled by a moderator. The group members created a round table, and a whiteboard was used by the moderator from the organizing team to document the important points. Each group discussed its assigned topic for approximately 90 minutes and subsequently presented the main insights and outcomes of their discussions through a 10-

minute presentation. The content of each presentation, along with the points documented on each group's board by the moderators, formed the primary data source for the Results section.

RESULTS & DISCUSSIONS

PRIORITIZED RESEARCH DIRECTIONS AND SOLUTIONS

Below is a summary of the group presentations regarding the discussions on their assigned research topics and the solutions they developed based on their expertise.

Foundations & Ecosystem

The discussion started with economic issues. Several challenges were raised. For example, new construction robots still have high costs in the beginning, and the expected return is not clear. Because of this, many contractors are still unsure about using these robots. Participants also pointed out that the industry still does not have enough clear data to show that robots work better than the usual methods. To build trust and support future investment, experts suggested running small test projects or case studies, such as Lean A3 problem-solving reports for robotics pilots. These tests should compare robot-based work with traditional work. Important points to check include how long each task takes, how many errors or rework cases appear, how much the total cost is during the whole period, and how well the process connects with BIM-based project management. They also noted that different stakeholders—such as contractors, tech companies, and project managers—should be involved in these tests. Their participation would help produce reliable, data-based results that show whether robots can truly bring efficiency and economic benefits. Experts noted that clear and well-planned pilot projects are needed to show the real return on investment on construction sites. They suggested using paid Proof of Concept (POC), since it can test the value of a system under real working conditions and check if it is both financially and operationally practical. They discussed several ways to verify the system, such as studying how long tasks take, or testing leasing and rental models to see how the robot performs in different types of projects. They also proposed important evaluation points, including performance, productivity, how close the tests are to real site conditions, sustainability, and the quality of training. The group stressed that human factors should also be part of the evaluation. This includes how quickly operators can learn the system and how well they adapt, not only technical results. They agreed that a shared validation process—where developers, contractors, and end users work together—is important to keep the tests realistic and relevant to actual site needs.

Finally, the group agreed that validation work should match clear use cases, adoption plans, and long-term goals. This way, pilot projects can not only demonstrate that the idea works, but they can also help build a solid scalable path for wider use of construction robots in the industry.

Human-Centered Design & Collaboration

The core of the session was discussing the adaptability and the practical reliability in human-robot collaboration. The session started with pointing out some concerns regarding the safety issues. Several participants noted the risks of human–robot accidents on constantly changing construction sites. In this regard, the group suggested taking several measures, such as the implementation of advanced sensors, cameras, and protective cages for construction robots.

Additionally, the importance of implementing well-trained algorithms and offering training sessions for the site workers was emphasized. Some members recommended performing digital risk analyses and simulating potential accident scenarios in advance to minimize unnecessary interaction between the robots and the humans on construction sites.

Participants also highlighted the importance of using access control systems, such as personalized passwords. They noted that, despite being a basic measure, personalized passwords can play a huge role in preventing unauthorized access and potential accidents on

the site. In addition, ergonomic design, particularly in relation to wearable robots, was addressed. Several participants expressed concerns about the long-term physical effects of these systems on workers. The group also agreed that clearly defined regulations for human–robot collaboration are needed to ensure safety and liability clarity. Several members of the group addressed the communication difficulties between humans and robots as another challenge for human-robot collaboration. In this regard, the group suggested developing simple, user-friendly interfaces and integrating several communication ways, such as visual, auditory, and gestural to the human-robot interaction. They also mentioned that LLMs can be used to address language barriers and improve mutual understanding between the robots and their operators. The group also discussed the topic of trust and acceptance; the experts highlighted that successful adoption depends on how comfortable humans feel working alongside robots. Participants proposed improving the robots' appearance, responsiveness, and communication tone to create a more natural interaction. Another way to build confidence and highlight real-world advantages of human-robot collaboration was described as providing workers with hands-on opportunities to interact with robots and gain the feeling and experience of the benefits from this interaction directly. Furthermore, a few members emphasized early education and cultural familiarization with robotics as a long-term solution. Defining clear use cases and required skillsets before starting to use robots and hiring competent and experienced engineers, project managers, and site workers were also among the points mentioned. Finally, the group discussed the economic aspects. A few members noted that high costs for materials, maintenance, and system development can prevent robot adoption in the industry. To address this challenge, the group members suggested gaining better market awareness, informed investment decisions (build, buy, or rent), and effective project management to optimize costs and resources.

Technology & Application

The discussion centered on the reality that construction sites change daily, making robots that can handle every new situation on site expensive. A practical path to address this challenge is human-robot collaboration (HRC) with bounded autonomy: robots should use continuous sensing, real-time map updates, and adaptive planning to minimize resets, with humans inputting instructions through a Graphical User Interface (GUI) and intervening when needed. The group presented a simple stack as shown in Figure 4—inputs from GUI and perception of the robots' flow into a Knowledge/Process layer that is predefined, and further onwards to the motion control unit and the actuators, with outputs as the actions of the robots—aimed at reliability rather than maximal autonomy.

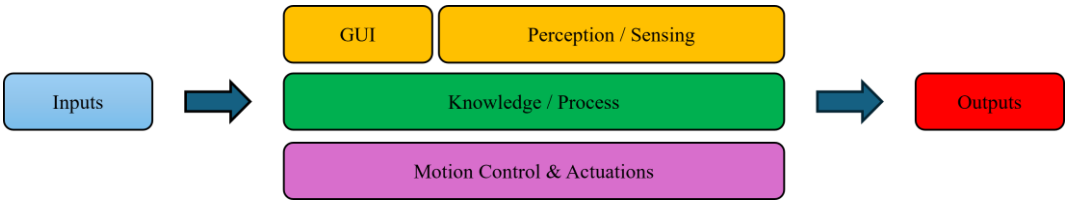

Figure 4: Human–robot collaboration system stack for bounded autonomy

A second thread focused on choosing the right tasks to automate. The group combined three lenses—human, design, and environment—into a single difficulty score and compared that against a development-cost scale from L0 to L6 (where L0 means low cost to automate and L6 means high cost). The guidance is to start with high-difficulty, mid-cost opportunities and to avoid high-cost, low-difficulty candidates, such as tile laying. Within the Knowledge/Process layer, Building Information Modeling (BIM) context, method statements, and learned skills or behavior trees work together and should be treated as complementary inputs rather than competing ones. To put this into practice, the group recommended short, on-site pilots that stress daily map refresh and adaptive planning under routine disruptions. Each pilot should

track a small, comparable set of metrics and key performance indicators (KPIs). These could include time to a stable map after changes, path-completion rate when the site shifts, frequency of human interventions, near-miss incidents, installation time and rework relative to the baseline, and total cost of ownership across trials. The proposed KPIs can be directly linked to Lean performance indicators such as Cycle Time (e.g., time to stable map), Percent Plan Complete (PPC) (e.g., path-completion reliability), and Waste Reduction (e.g., rework relative to baseline). Furthermore, they can let owners and regulators define acceptance thresholds and give contractors and technology providers the confidence to scale Human–Robot Collaboration (HRC) where reliability and Return on Investment (ROI) are demonstrated.

Implementation & Innovation Pathways

The discussion began with concerns about how well robots can operate independently and move safely in busy urban construction sites. Participants noted that autonomous robots still face difficulties navigating environments with moving workers, machines, and obstacles, raising questions about their reliability and safety. They highlighted the importance of setting measurable benchmarks, such as how often robots avoid obstacles, how frequently they need to replan their routes, and how quickly they complete tasks, based on realistic simulations or field tests. Collecting such data is essential to show that autonomous systems can meet on-site safety and scheduling requirements and justify continued investment in construction robotics.

The experts built on these ideas by presenting an integrated research framework for autonomous navigation in dynamic urban construction sites. Their approach combines 4D BIM, robotic perception, and intelligent path planning to improve both efficiency and safety. They explained that the study focuses on two types of construction settings: high-rise complex buildings and low-rise warehouse-style sites. These types can be used to test how well the system scales and adapts to different conditions. In their method, static paths are first simulated using 4D BIM models, while dynamic elements and real-time obstacle detection allow for continuous path optimization. Potential bottlenecks, such as vertical transport or restricted access areas, can then be identified and addressed through adaptive routing and automated zoning strategies that clearly separate human-only, robot-only, and mixed working zones.

The experts further elaborated on the system's situation awareness and localization components, which utilize trained models sensitive to environmental and human parameters such as temperature, motion, and uncertainty, all supervised and validated by human operators. They highlighted the use of computer vision and multi-sensor data fusion to achieve high-accuracy localization for multiple robots operating simultaneously within complex construction environments. In terms of implementation, the group proposed a phased approach. In the short term, dynamic "4D as-built BIM" updates, powered by daily point cloud or photogrammetric scans, would keep the digital model synchronized with actual site conditions. These continuous updates would allow robots to share maps, detect obstacles, and coordinate zoning autonomously. In the long term, the vision extends toward a fully automated construction ecosystem, in which offsite or aerial "robot-oriented factories" autonomously fabricate and assemble building components. This concept, referred to as the Sky Factory Zeppelin Selection, envisions a fundamental transformation of construction workflows and brings together autonomy, safety, and scalability for the next generation of urban construction.

CONCLUSION

This paper presented an LLM-assisted workshop methodology for turning direct expert input into actionable insights for addressing the challenges in construction robotics. This workshop, scheduled annually, was designed to serve as a medium to foster action learning in construction robotics. The methodology was implemented during a two-day workshop in Germany, attended by over 110 leaders in construction robotics. The workflow integrates direct participant input

and data from the literature through an automated process to identify potential research directions. Furthermore, it is followed by a democratic polling session to receive expert insights on prioritizing these research directions. Subsequently, the experts are grouped with predefined criteria to discuss solutions for these challenges in four breakout groups, each with a different theme on construction robotics. Implementing an AI-assisted methodology in a live workshop setting aligns with the Lean principle of Respect for People by ensuring that all participant inputs are systematically captured and transparently synthesized (fair representation). This approach reduces potential biases and values diverse perspectives. Furthermore, incorporating a democratization step respects individual opinions by enabling the participants to actively prioritize the topics they consider most significant. Finally, the breakout sessions were moderated such that the participants' goals in developing actionable solutions were aligned and followed the consensus. From a Lean Construction perspective, this study demonstrates how AI-assisted workflows can enhance stakeholder engagement, reduce information waste, and support structured collaborative learning environments.

The process of the workshop development methodology provided several practical lessons that are relevant for future applications. First, the original workflow relied on continuous internet connectivity and technical availability for real-time feedback collection. The workshop proved that such dependencies create vulnerabilities and highlighted the necessity of designing Plan-B strategies. In this context, the data from the relevant literature in the specific areas served as a compensation to ensure continuity of the method. However, it should also be noted that the data from the literature cannot fully represent the diversity of the expert feedback that could have been submitted. Second, time constraints in a limited workshop setting can adversely affect the data collection and analysis process. Additionally, the workshop highlighted the importance of creating a balance between AI-usage and human judgment. Despite the recent advancements in LLMs and their ability to structure and analyse a huge amount of input data, it goes without saying that the moderated expert interpretation and discussion cannot be replaced with AI to define actionable and practical plans. Therefore, the hybrid nature of this methodology proved efficient in maintaining meaningful results.

The lessons and experiences documented in this workshop will guide the planning and organization of future events and will create a foundation for the integration of AI and LLMs in similar occasions. Furthermore, this paper contributes by introducing a digital and adaptable way to directly benefit from expert input in identifying the action plans for the challenges relevant to construction robotics. In this context, the findings provide valuable action plans to address the adoption challenges across each category. It is important to note that, while certain adoption barriers are specific to individual categories, recurring concerns across multiple themes, such as economic considerations, indicate an overlap of challenges across multiple themes. These recurring themes may require further investigation and may serve as subjects for discussions in future workshops. Future studies can focus on implementing different workflows or more advanced LLMs to gain enhanced results. Moreover, comparative studies could be conducted to evaluate the efficiency of AI-based workflows relative to traditional workshop formats. Incorporating a feedback collection mechanism, such as online surveys, into the workflow can enable continuous improvement in successive workshops. Finally, the methodology presented in this paper may be extended and implemented in workshop settings across a broader range of other disciplines.

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