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Robotics and Automated Systems in Construction

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Abstract*:* Construction robotics and automatic aims to revolutionize the construction industry by utilizing robotic system and advanced automation technologies to address labor shortages, improve safety, enhance productivity, and achieve higher quality standards by automating repetitive tasks, precise material handling, and complex construction processes, thereby transforming the traditional manual labor- intensive approach to building construction. A mixed research method was employed combining literature review, qualitative and quantitative data collection and analysis. Three focus groups with 28 experts and an online questionnaire were conducted. Principal component and correlation analyses were conducted to group the identified factors and find hidden correlations. The main identified challenges were grouped into four categories and ranked in order of importance: contractor-side economic factors, client-side economic factors, technical and work-culture factors, and weak business case factors. No strong correlation was found among factors. This study will help stakeholders to understand the main industry-specific factors limiting the adoption of robotics and automated systems in the construction industry. The presented findings will support stakeholders to devise mitigation strategies

Keywords: Automated construction, Robotics, Addictive manufacturing, Exoskeletons, Autonomus vehicles, Off-site construction, 3d printing, sensor networks, machine learning, construction simulation, site surveying drones, integrated system

I. INTRODUCTION

Robotics and automated systems in construction refer to the use of robots, machines, and computer systems to perform construction tasks with increased efficiency, accuracy, and safety. These systems can automate various construction processes, such as building, excavation, and material handling.

Benefits

1. Increased Productivity : Robotics and automated systems can work around the clock without fatigue, increasing construction speed and productivity.
2. Improved Accuracy : Automated systems can perform tasks with high precision, reducing errors and improving overall quality.
3. Enhanced Safety : Robots and automated systems can take on hazardous tasks, reducing the risk of Injury to human workers.
4. Cost Savings : Automated systems can reduce labour costs, minimize waste, and optimize material usage.
5. Environmental Benefits : Robotics and automated systems can help reduce the environmental impact of construction by minimizing waste and optimizing resource usage.

Applications

1. Building Construction: Robotics and automated systems can be used for tasks such as brick laying, concrete finishing, and glazing.
2. Excavation and Demolition : Automated systems can be used for excavation, demolition, and site preparation.
3. Material Handling : Robotics and automated systems can be used for material transportation, storage, and retrieval.

4. Inspection and Maintenance : Automated systems can be used for inspection, maintenance, and repair of building sand infrastructure.

Types of Robotics and Automated Systems

1. Industrial Robots : Programmable robots designed for specific tasks, such as welding, assembly, and material handling.
2. Autonomous Systems : Systems that can operate independently, such asself-driving excavators and drones.
3. Robotic Arms : Programmable arms that can perform tasks such as assembly, welding, and material handling.
4. Automated Guided Vehicles(AGVs) : Vehicles that can navigate and transport materials autonomously.

Challenges and Future Directions

1. Integration with Existing Systems : Integrating robotics and automated systems with existing construction processes and systems.
2. Cybersecurity : Ensuring the security of automated systems and protecting against cyberthreats.
3. Workforce Training : Training workers to operate and maintain robotics and automated systems.
4. Regulatory Frame works : Developing regulatory frameworks to govern the use of robotics and automated systems in construction.

II. ROBOTICS AND AUTOMATED SYSTEMS IN CONSTRUCTION

2.1. Off-site automated prefabrication systems

This category includes various technologies that produce building components at off-site locations in an automated manner. The main objective of these systems was to improve the quality of prefabricated building components and took inspiration from the use of robots in other manufacturing sectors. These technologies include building component manufacturing (BCM) approaches, which transform materials (concrete, bricks, wood, steel, etc.) and low-level components into high-level building components. For example, concrete prefab elements, steel trusses, wood structural elements, wall, floor and roof sections, etc. There are also large-scale prefabrication (LSP) approaches, which combine high-level building components into finished entire building modules (e.g. bath or kitchen modules). This category also includes additive manufacturing techniques, also known as 3D printing. There is a large number of publications reported in literature regarding the use of additive manufacturing techniques in the construction industry. The prospects, challenges and benefits of 3Dprinting technologies for the construction industry have been widely reported in literature. The main challenges identified include the development of appropriate materials and the lack of understanding of the material mechanical performance. Various potential applications have been identified, ranging from the creation of optimised and customised building parts to in-situ repairs. Additive manufacturing technologies have been improving rapidly, and now, it is possible to print large scale components as well.

2.2. On-site automated and robotic systems

This category includes automated and robotic systems that can be used directly on the construction site to create structures and buildings. The first type of systems used were single task construction robots (STCRs), which can execute a single task in a repetitive manner. A typical example of this type of robots is robotic arms used in automotive manufacturing. These types of robotic arms are usually mounted in movable platforms and are used on site to perform simple tasks. For example , presented a scaffold integrated robotic system that enables a robotic arm to be mounted in a scaffold, presented a robotic system that paint walls , presented a mobile robotic arm that assembles bricks, and presented a concrete spraying robotic system. This approach is very flexible because it could be easily adapted to be used in combination with other traditional construction methods. However, this approach generates other challenges such as the need for additional health & safety requirements, the difficulty to parallelise and to integrate with human workers activities, and the lack of integration with downstream and upstream activities. Robotic on-site factories have been developed to address these challenges. They are factory-like environments on construction sites. Its main intention is to integrate standalone STCRs into controlled environments that enable the implementation of networked robot systems, in which various robots can be used for different types of task in an automated manner, resembling a manufacturing production line. In this same note, research has been carried out that seeks to enable collaboration among various robots to complete more complex tasks. For example, presented a feasibility study to use various robots to build masonry structures. presented a hardware-software system that enables small robots to assemble and disassemble plastic blocks.

2.3. Drones and autonomous vehicles

This category includes terrestrial, aerial or nautical vehicles that can be piloted remotely, or which are autonomous (i.e. no conductor is required). These vehicles can be used for various tasks including (1) accessing extreme and dangerous environments, thus removing human workers from high-risk areas; (2) surveying and monitoring tasks; and (3) automated excavating, demolition and transportation of materials.

III. EXOSKELETONS

An exoskeleton is awearable robotic device that provides support, stability, and enhanced strength to the user's body. In construction, exoskeletons can be used to assist workers in performing physically demanding tasks, reducing fatigue and injury.

Types of Exoskeletons

1. Passive Exoskeletons : Provide support and stability without motorized assistance.
2. Active Exoskeletons : Use motors or actuators to provide additional strength and support.
3. Hybrid Exoskeletons : Combine passive and active components.

Applications in Construction

1. Material Handling : Exoskeletons can assist workers in lifting and carrying heavy materials.
2. Demolition and Excavation : Exoskeletons can provide support and stability for workers performing physically demanding tasks.
3. Welding and Assembly : Exoskeletons can assist workers in holding heavy tools or equipment.
4. Inspection and Maintenance : Exoskeletons can provide support and stability for workers performing tasks at heights.

Benefits

1. Reduced Fatigue : Exoskeletons can reduce worker fatigue and discomfort.
2. Increased Productivity : Exoskeletons can enable workers to perform tasks more efficiently.
3.Improved Safety : Exoskeletons can reduce the risk of injury from heavy lifting or falls.
4. Enhanced Accessibility : Exoskeletons can enable workers with disabilities or injuries to perform tasks.

Challenges and Future Directions

1. Cost and Affordability : Exoskeletons can be expensive, making them inaccessible to some construction companies.
2. User Acceptance : Workers may be hesitant to use exoskeletons due to concerns about comfort, safety, or job replacement.
3. Regulatory Frame works : There isa need for regulatory frame works to govern the use of exoskeletons in construction.
4. Technological Advancements : Advancements in materials, design, and control systems can improve the performance and affordability of exoskeletons.

IV. RESEARCH METHODOLOGY

A mixed research method was used that combines (i) literature review, (ii) qualitative data collection and analysis, and (iii) quantitative data collection and analysis. This type of mixed research methods has been proved as powerful tools to investigate complex processes and systems in other sectors. This type of mixed methods can also be very beneficial in the AEC area, in which qualitative results can support and guide the quantitative data collection and analysis. Combining qualitative and quantitative analyses helps to explain, categorise and generalise findings. The first step was

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to conduct a review of the existing literature on factors that limit the adoption of robotics in the construction industry. In addition to this, focus group discussions (FGs) (qualitative analysis) were used to identify limiting factors that may not have been identified in the literature. Findings from both activities were compiled into a single list of factors. In the second step, quantitative analysis, the results from the previous step were used to design a quantitative data collection instrument (i.e., questionnaire). The questionnaire was administered to specialists in the AEC area in European countries. The identified factors were ranked and categorised (using component analysis), and correlations among them were investigated using the results of the questionnaire. A reliability analysis was carried out on the questionnaire results to validate the internal consistency of the results. Lastly, using the results of the qualitative and the quantitative analysis relevant insights into the factors limiting the adoption of robotics in the construction industry were drawn and explained (factor understanding). The results of this study can then be analysed based in a local context (e.g. a specific country, company and project) and mitigating strategies can be devised to address the specific challenges that limit the adoption of robotics in the construction industry.

V. QUALITATIVE SAMPLING AND ANALYSIS

Qualitative sampling and analysis involve non-numerical data collection and analysis methods to gain insights into the robotics and automation system construction process.

Sampling Methods

1. Purposive Sampling : Selecting participants or cases that are intentionally chosen to provide rich, detailed insights.
2. Snowball Sampling : Identifying initial participants who then recommend others with relevant expertise or experiences.
3. Case Study Sampling : Selecting a specific case or project to study in-depth.

Data Collection Methods

1. Interviews :Conducting in-depth, semi-structured, or structured interviews with experts, stakeholders, or users.
2. Observations :Observing robotics and automation system construction processes, workflows, or user interactions.
3. Document Analysis : Analyzing project documents, reports, or technical specifications.

Data Analysis Methods

1. Thematic Analysis : Identifying, coding, and categorizing themes and patterns in the data.
2. Content Analysis : Analyzing text, image, or video data to identify patterns, themes, or meanings.
3.Narrative Analysis : Analyzing stories, experiences, or accounts to identify themes, patterns, or meanings.

VI. QUANTITATIVE SAMPLING AND ANALYSIS

Quantitative sampling and analysis involve numerical data collection and analysis methods to measure and quantify aspects of the robotics and automation system construction process.

Sampling Methods

1. Random Sampling : Selecting participants or cases randomly to ensure representativeness.
2. Stratified Sampling : Dividing the population into subgroups and sampling from each subgroup.
3.Systematic Sampling : Selecting every nth participant or case from a list or database.

Data Collection Methods

1. Surveys : Conducting online or offline surveys to collect numerical data from a large sample.
2. Experiments : Conducting controlled experiments to measure the effect of specific variables.
3. Sensor Data : Collecting data from sensors, such as temperature, pressure, or vibration sensors.

Data Analysis Methods

1. Descriptive Statistics : Calculating means, medians, modes, and standard deviations to summarize the data.
2. Inferential Statistics :Using statistical tests, such as t-testsor ANOVA, to make inferences about the population.
3. Regression Analysis : Modeling the relationship between variables using linear or nonlinear regression.

By combining qualitative and quantitative sampling and analysis methods, researchers and Practitioners can gain a more comprehensive understanding of the robotics and automation system construction process and develop more effective solutions to improve its efficiency, productivity, and quality.

VII. IMPLICATION FOR PRACTICE

Design and Development

1. Modular design : Design robotic and automation systems with modular components to facilitate Easy maintenance, upgrade, and reconfiguration.
2. Human-machine interface : Design intuitive and user-friendly interfaces to enhance operator experience and reduce errors.
3. Safety considerations : Incorporate safety features and protocols to prevent accidents and ensure Operator safety.

Construction and Installation

1. Site preparation : Ensure proper site preparation, including cleaning, leveling, and marking, to facilitate efficient installation.
2. Installation planning : Develop detailed installation plans to minimize downtime and ensure Smooth integration with existing systems.
3. Quality control : Implement quality control measures to ensure that systems are installed correctly and function as intended.

Operation and Maintenance

1. Operator training : Provide comprehensive training to operators to ensure they can safely and effectively operate and maintain robotic and automation systems.
2. Predictive maintenance : Implement predictive maintenance strategies to minimize downtime and optimize system performance.
3. Continuous monitoring : Continuously monitor system performance to identify areas for improvement and optimize operations.

Safety and Risk Management

1. Risk assessment : Conduct thorough risk assessments to identify potential hazards and develop Strategies to mitigate them.
2. Safety protocols : Establish and enforce safety protocols to ensure operator safety and prevent accidents.
3. Emergency preparedness : Develop emergency response plans to ensure prompt and effective response to incidents.

Collaboration and Communication

1. Stake holder engagement : Engage with stakeholders, including operators, maintenance personnel, and management, to ensure that their needs and concerns are addressed.
2. Clear communication : Establish clear communication channels to ensure that information is shared effectively and efficiently.
3. Collaborative problem-solving : Foster a culture of collaborative problem-solving to ensure that Issues are addressed promptly and effectively.

Sustainability and Environmental Considerations

1. Energy efficiency : Design and operate robotic and automation systems to minimize energy consumption and reduce environmental impact.

2. Material selection : Select materials and components that minimize environmental impact and promote sustainability.
3. Waste reduction : Implement strategies to minimize waste generation and promote recycling.

Future-Proofing and Innovation

1. Stay up-to-date with industry developments : Stay informed about the latest advancements and trends in robotics and automation.
2. Encourage innovation : Foster a culture of innovation and experimentation to drive continuous improvement.
3. Invest in research and development : Invest in research and development to stay ahead of the curve and develop new technologies and solutions.

VIII. CONCLUSION

The integration of robotics and automation in construction has the potential to transform the industry by improving efficiency, productivity, and safety. The use of exoskeletons, robotic arms, and automated systems can reduce the physical demands of construction work, minimize errors, and enhance overall quality.

However, there are challenges to be addressed, including cost, user acceptance, regulatory frameworks, and technological advancements. To overcome these challenges, it is essential to adopt a holistic approach that considers the technical, social, and economic aspects of robotics and automation in construction.

By embracing innovation, investing in research and development, and fostering collaboration between stakeholders, the construction industry can unlock the full potential of robotics and automation. This will not only improve the efficiency and productivity of construction processes but also enhance the safety and well-being of construction workers. Ultimately, the future of construction will be shaped by the effective integration of robotics and automation, enabling the industry to build faster, safer, and more sustainably.

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