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LEAN CONSTRUCTION WASTE REDUCTION THROUGH THE AUTONOMOUS VEHICLE TECHNOLOGY

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ABSTRACT

In the automotive industry, autonomous vehicles (AVs) are an advanced innovation that has the potential to revolutionise the existing transportation system significantly. In addition, AVs provide benefits for society, the economy, and the environment. As far as Lean Construction (LC) is concerned, these features appear promising. LC's primary objective is to minimise the waste of resources, time, and effort. This study examines the potential contribution of AVs to LC through two exhaustive rounds of literature review. The research aims to establish the links between AVs and the overarching LC philosophy and principles. The first round of the literature review identified that AVs could reduce waste in three areas: inventory, transportation, and waiting time. Moreover, they can support solutions to environmental concerns. Additional literature reviews have identified five potential approaches for a new technology that can be applied to the construction industry to enhance the implementation of AVs. As well as the anticipated developments in each case are discussed accordingly. The practical implications of the findings are that AVs can reduce waste and cost, increase efficiency and productivity, and help create a more sustainable construction industry. According to the study, the construction industry should take a proactive approach to implementing AVs.

KEYWORDS

Lean construction, AVs, transportation, waste

INTRODUCTION

The fully advanced autonomous vehicles, known as driverless cars, are capable of identifying their surroundings by increasingly dependent on sophisticated technology to replace the actual human driving tasks, decisions, and behaviors (Ma et al., 2020). It is able to travel independently to various locations while excluding any human driving assistance (Litman, 2017). In fact, the Society of Automotive Engineers (SAE) has developed the SAE international standards J3016, which illustrates the AV's six categories, starting from the most basic (nonautonomous) to the most advanced vehicle (fully autonomous) (SAE International from SAE J3016™, 2021). This innovation offers a major breakthrough in the existing transportation system to benefit society,

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the economy, and the environment. It also offers improvements in automated driving-assist characteristics and capabilities with enormous advantages for the AV lower levels (Katrakazas et al., 2015; Le Vine et al., 2015).

It is anticipated as a realistic solution for future transportation that will increase traffic efficiency, decrease fuel consumption, and importantly reduce carbon dioxide emissions, to name a few. It is, also largely relies on a computerised system equipped with advanced technologies that have been built inside the vehicle (Parkin et al., 2018). Furthermore, it may communicate traffic information among cars through advanced communication equipment utilising advanced Internet Technologies (IT) via a cloud service. Additionally, super-fast communication technology between cars that are based upon the Fifth Generation (5G) network to improve its vision in a fully secured manner (Storck & Duarte-Figueiredo, 2020). Vehicles are considered the heart of land transportation, as well as play a vital role in the construction industry. However, transportation has been identified as one of the leading waste types in the LC. It, therefore, requires more collaborative efforts to minimise its impact on society, the economy, and the environment. Also, to achieve the fundamental philosophy and principles of lean construction.

Lean construction (LC) presents “a way to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value” (Koskela et al., 2002). Lean construction recognises eight types of waste in the construction sector (Aziz & Hafez, 2013; Koskela, 2004; Sarhan et al., 2017) as follows:

1- Overproduction: Linked to the creation of a larger volume than requested or earlier than desired, which results in a waste of work efforts and materials.
2- Substitution: Financial waste produced by the replacement of a less-priced product with a more costly one, easy duty performed by an over-skilled individual, or the use of extremely advanced technology for simpler jobs.
3- Waiting time: Related to idle time resulting from a shortage of material supply chain coordination and levelling, as well as the speed of activity by subgroups or equipment.
4- Transportation: The internal materials flow in construction sites could result from improper handling, the application of insufficient machinery, or poor passage conditions. It has the following significant consequences as loss of manpower, energy, storage area, and potential material loss while transfer.
5- Processing: Associated with the processor (conversion) operation, which can possibly be prevented by adjusting building technology.
6- Inventories: Relating to overstocks or unused stockpiles that cause waste of materials.
7- Movement: Deals with activities performed by employees that are needles in the workplace.
8- Production of defective products: It occurs when the final result fails to fulfil the quality standards.

As indicated earlier, the AVs provide enormous features that could boost the entire land transportation sector. However, transportation has been identified as one of the main waste types in the LC. Therefore, the research aims to explore the links between the use of AVs and LC fundamental philosophy and principles, which might offer a significant waste reduction in some of the earlier identified and widely agreed areas. This could consolidate the LC philosophy and support its concepts overall. Nevertheless, AV technology is still in its infancy stages of development, and studies that provide information on this matter are lacking. By examining the potential contributions of AVs in the LC industry, this study seeks to identify any further potential reduction in the LC waste types through the deployment of AV innovation. It also provides five different approaches to assist the decision-makers in deploying the AVs based on their risk assessments (on a governmental scale) in order to maximise their value in lean construction.

METHODOLOGY

Using a two-stage research design, this study investigates how AVs can contribute to lean construction, as shown in Figure 1.

In the *first phase*, a comprehensive literature review was conducted to identify the current state of the art in autonomous vehicle features, as the research parameter has been selected to search the "autonomous vehicles" AND "technology features" terms in google scholar to end up with 337 articles ranging from 2015 to present. Furthermore, the research team has analysed the identified articles based on AV aspects that could contribute to the reduction of waste recognised by lean construction to end up with 23 related articles. By utilising this information, the team developed comprehensive analogies linking the prominent features of AVs with the purpose of lean construction in order to reduce waste.

In the *second phase*, a literature review was conducted to identify existing strategies that could be used to support the application and utilisation of AVs in construction supply chain management. A set of keywords of "Autonomous vehicle" AND "deployment strategies" has been searched on google scholar from 2015 to date to end up with 260 related articles. It led us to identify common strategies for the application of AVs. Based on the results of the second literature review round and the best practices reported, we have identified a comprehensive set of guidelines that can be applied to the construction industry to assist in the implementation of AVs. These guidelines provide an outline of the necessary steps to be taken in order to successfully incorporate AVs into construction supply chain management based on the situation and risk acceptance level by the industry. They should be used to ensure the successful adoption of these vehicles and ensure that the full potential of their use is realised.

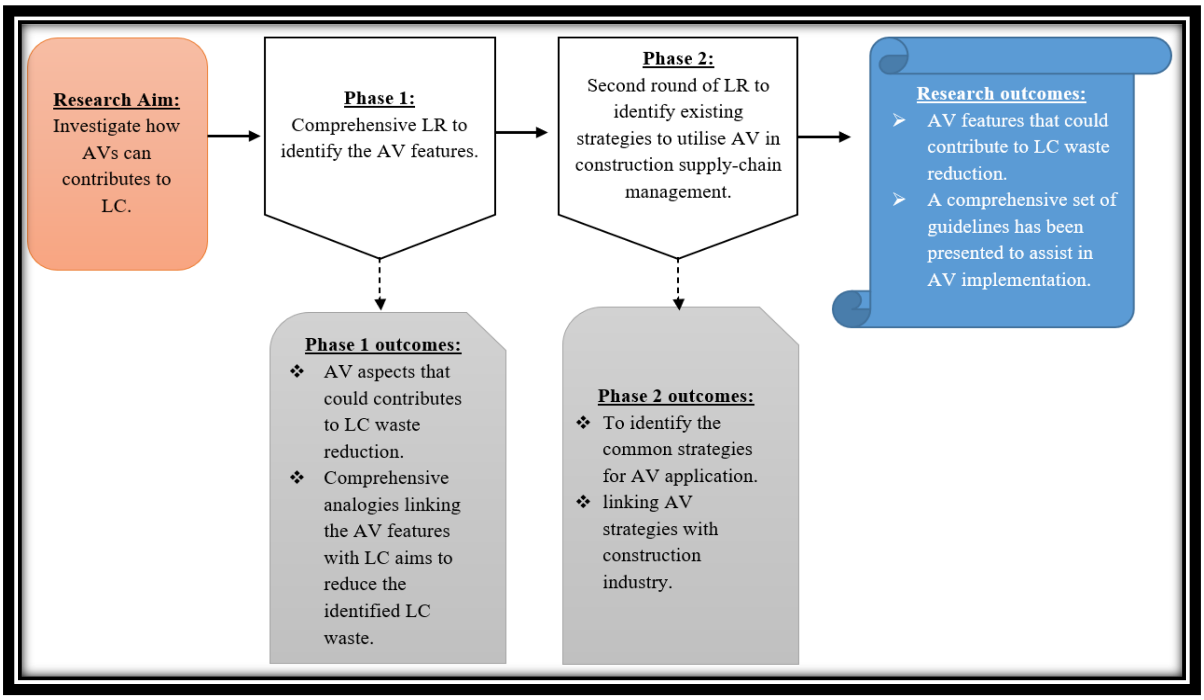

Figure 1: Research Outcomes

AVS AND THEIR STANDARDS

AVs or driverless vehicles are laying the foundation for future sustainable transportation (Chehri & Mouftah, 2019; Owais et al., 2022; Zou et al., 2021). It has the ability to navigate to numerous locations while responding quickly to signs, humans, and animals. It is also capable of overcoming unexpected obstacles independently (Greenblatt, 2016; Xing et al., 2021). The AV is anticipated to reduce transport emissions, vehicle journeys, and occupied road vehicles by 66, 30, and 28 per cent, respectively (Namboodiri, 2018). It could, also, reduce parking spots by 44 per cent and up to 87 per cent of road accidents. Therefore, the emergence of AVs could offer several benefits for society, the economy, and the environment.

It is predicted, for instance, to boost road capabilities by up to 100 per cent to accommodate more vehicles on the roads and smooth traffic patterns by up to 20 per cent, reducing unnecessary expenditure, fuel consumption, and time waste on the roads (Sundquist, 2016). Besides, it is expected that up to 75 per cent of fully driven AVs will occupy the roads by 2040 (Luttrell et al., 2015). Moreover, AVs are predicted to have around 70 per cent impact on large transportation vocations in the US and Europe by 2030 (Baratta, 2021). Researchers estimate that five per cent of this innovation would be expected to improve road congestion associated with stop-and-go behaviour, which would result in a 60 per cent reduction in transport emissions (Stern et al., 2018). Resulting in timesaving for people, and a decrease in the vehicle journey period on the roads, which will greatly reflect on transportation emissions.

As humans constantly depend on advanced technologies to replace traditional driving techniques and unexplained human driving behaviours, AV innovation could be a novel solution since they are able to assess their environment and proceed accordingly (Ma et al., 2020). Furthermore, despite the necessity of human participation in traditional driving tasks, AV could fully replace traditional driving to increase human efficiency in other activities (Litman, 2017). Therefore, the Society of Automotive Engineers (SAE) global standardisation J3016 has been issued aiming to define the six AV layers (SAE International from SAE J3016™, 2021-04-30). Starting with the least sophisticated layer, which requires the full involvement of the driver (nonautonomous), and proceeding up to the most sophisticated layer, which excuses the driver from duty (fully autonomous). These global standardisation levels had "become a de facto global standard adopted by stakeholders in the automated vehicle technology", in 2018 (Hopkins & Schwanen, 2021). Therefore, the SAE international standards aimed to illustrate the AV levels to aid in embracing the technological revolution and assist the deployment of AV locally.

WASTE REDUCTION THROUGH THE USE OF AVS

The adoption of AVs allows lean construction to further enhance one of its main objectives associated with waste reduction/elimination. It can lead to increased efficiency and productivity in the construction industry, as well as an environmental impact reduction. According to our analogical analysis, three primary waste categories could significantly benefit from automated vehicles:

1- **Inventory waste:** It presents a common waste in the construction industry and a challenge for lean construction practices (Ansah et al., 2016). It is the goal of LC to reduce waste by keeping inventory levels low, and ordering only what is required when the need arises. This goal is challenged by the risk of inadequate supply on-site, burglary, degradation, and material damage (Aziz & Hafez, 2013). To prevent these challenges, in the construction industry, it is often necessary to order materials in advance and in excess to ensure that they are available when needed. This excess inventory takes up valuable space, ties up capital, and increases the risk of obsolescence (Lim YenWui et al., 2009). Therefore, the collaboration between advanced automotive technology and lean construction could help reduce excessive inventory problems as a type of construction waste by facilitating inventory management and reducing uncertainty around resource availability. Also enables the accurate tracking of resources in real-time and improves delivery times.

- *Improved delivery:* The use of AVs, such as advanced driverless trucks, can improve the speed and accuracy of delivery and reduce the uncertainty surrounding the delivery of materials and equipment (Teoman, 2020). With autonomous vehicle delivery, there will be no need to keep excessive inventory in storage, which can be costly and inefficient as identified as one of the waste types in LC. This ultimately leads to significant cost savings and operational efficiency, as well as improved customer satisfaction with faster and more reliable deliveries.
- *Better tracking:* By utilising autonomous technology, materials, and equipment can be tracked from the supplier to the construction site, providing a more accurate picture of what materials are available and where they are located through the Internet of Things (Liu et al., 2019). As a result of collaboration with AVs, losses, damages, and materials are minimised, and unnecessary lead times are avoided, which results in improved project outcomes and enhanced cost efficiency.

2- **Transportation waste:** AVs can play an instrumental role in reducing transportation waste by providing more efficient, safe, and sustainable solutions. In addition to the improved delivery schedules discussed in the previous item, AVs may also contribute to further reduction of transportation waste in several ways, including:

- *Increased capacity:* AVs have the ability to operate 24/7 without the need for rest breaks, allowing more materials to be transported in a shorter amount of time. Additionally, they can be used in hazardous conditions where manual drivers cannot operate (Teoman, 2020). They can also be used to transport large amounts of materials in one trip. Furthermore, they can be operated more efficiently than manual drivers, resulting in fewer trips and better materials delivery (Heutger & Kueckelhaus, 2020).
- *Enhanced safety:* AVs can reduce the number of accidents on the job site, minimising the risk of injury to workers and reducing the potential for delays (Fagnant & Kockelman, 2015). AVs use sensors and cameras to detect their environment and navigate around obstacles (Parkin et al., 2018). This eliminates human error and increases safety by ensuring that the vehicles are operating in compliance with safety regulations independently.
- *Lower emissions:* AVs can be designed to be more energy efficient than conventional vehicles, thereby reducing their carbon footprint and the overall impact of transportation on the environment (Massar et al., 2021). AVs use advanced navigation and control systems that allow them to optimise their routes autonomously, resulting in less wasted energy and fewer emissions (Weimerskirch & Dominic, 2018). At any point in time, the AVs engine must use an efficient design because their need for efficiency in the engine is driven by timeless concerns such as environmental sustainability, resource scarcity, economic benefits, and technological innovation. As autonomous vehicles remain a relatively younger technology, they keep offering significant opportunities for innovation and advancement. By improving the efficiency of engines and powertrains, manufacturers can develop new and innovative technologies that can further improve the performance and efficiency of AVs, which further contributes to emission waste reduction.

- *Better coordination:* AVs can be integrated with other management systems, such as construction supply chain management, allowing for real-time monitoring of delivery schedules and reducing the potential for bottlenecks or other delays (Sharm, 2022).

3- **Waiting time:** This is another challenge in the construction industry and presents a major waste source as discussed under LC (Lim YenWui et al., 2009). It can result in higher costs, reduced efficiency, and decreased overall project productivity (McBride, 2003). Implementing AVs can contribute to the reduction of waiting time in several ways, including the following:

- *Reduce delivery waiting times*: AVs can deliver materials to the job site more frequently and more accurately, decreasing the wait time for materials to arrive, and cutting logistic costs (Xiaosheng & Hamzeh, 2020). AVs are able to calculate the most efficient route to the job site independently and can travel non-stop, which reduces travel time. Also, as time passes and technology becomes more accessible, the cost is expected to reduce. In addition, AVs do not require a human driver to operate the delivery vehicle. Therefore, the driver could be relocated to another construction site activities to increase construction performance and reduce unnecessary expenditure. For instance, driver expenditures account for a significant portion of total freight journey expenses, accounting for approximately 40 per cent of truck operational expenses in a high-wage nation (Engholm et al., 2020). The logistic cost might be significantly decreased through autonomous vehicles.
- *Improve equipment utilisation*: AVs can be used to transport equipment between job sites, reducing the wait time for equipment to be available on a specific job site (Gružauskas et al., 2018). AVs can provide a continuous flow of equipment to job sites, allowing for faster completion of projects. Furthermore, AVs can reduce the amount of manual handling of equipment which can lead to fewer accidents and improved safety.
- *Streamline transportation*: AVs can be programmed to follow the most efficient route so that less time is lost in traffic or on non-optimised delivery routes (Namboodiri, 2018). Autonomous vehicles have access to more advanced mapping and navigation techniques. Companies like TomTom are making automated driving more comfortable, efficient, and safer by offering technology that aids AV planning in advance and acts as a security net for sensors whenever vision and situation are unacceptable (Strijbosch, 2018). TomTom's technology is scalable and cost-effective, seamlessly integrating with internal systems, and currently powers autonomous driving for leading car manufacturers. Besides, Nvidia has also introduced its latest mapping platform, providing the AV sector with accurate mapping that covers more than 300 thousand miles of highway in Asia, Europe, and North America (Bellan, 2022). Moreover, they are equipped with a range of sensors, cameras, and other technologies that enable them to detect and avoid obstacles in real-time (Parkin et al., 2018). This means that they can make on-the-fly route adjustments to avoid traffic congestion or road closures, without requiring any input from the driver.
- *Enhance coordination*: Through the use of IoT, AVs can be integrated with other construction management systems, enhancing coordination and reducing the risk of bottlenecks (Sharm, 2022). With the use of IoT technology in AVs, it is possible to keep track of a number of different aspects of the delivery process. These aspects range from loading and unloading to the route taken and the arrival schedule of the delivery without the requirements of manual updates. This data can be used to reduce the risk of delays or bottlenecks.

Besides increasing productivity and efficiency, automated vehicles can also be environmentally friendly. Despite the LC philosophies of "respect for people", "maximizing value while minimizing waste", and "continuous improvement" (Do, 2022), sustainability and lean methodologies tend to clash whenever the supply chain is geographically expanded and participates in carbon dioxide emissions (Sertyesilisik, 2016). As the research aims to assist lean construction in achieving one of its primary objectives, namely reducing and eliminating waste, AVs can also help LC to address environmental concerns as well. After illustrating the AV benefits and how collaboration with LC could aid to support its core philosophy, it is crystal clear that waste reduction could be achieved through AVs. This can provide tremendous value to the environment, the economy, and society as a whole.

STRATEGY TO IMPLEMENT AVS IN THE CONSTRUCTION INDUSTRY

Previously, it has been discussed how AVs can assist the construction industry in achieving LC objectives if they are adopted by this sector. For AV to be successfully adopted at the industrial level, it must be accepted at a higher governmental level. Nevertheless, many developed countries have not fully implemented AV due to unforeseen long-term risks such as safety, liability, and cyber security (Milakis, 2019; Taeihagh & Lim, 2019). Essentially, autonomous technologies are widely acknowledged for their benefits, but questions are raised about their deployment, hazards, and unanticipated outcomes (Taeihagh & Lim, 2019). In fact, several scholars have admitted that the adoption of new technology would surely result in some unexpected risks (Taleb, 2007; Clarke, 1999). These risks frequently result in major expenditures for the interested parties (Perrow, 1999). Therefore, safety, liability, and cybersecurity as risk factors remain significant challenges for the industry to adopt such innovation.

To overcome these challenges, five AV-related governing approaches are presented by Li et al. (2021), and Li et al. (2018), which define the potential scenarios when deploying new technology. The governance measures that decision-makers may use to manage risks associated with the deployment are intended to achieve optimal user advantages while reducing technology-associated risks. For this scenario, the proposed approaches for deploying AV innovation in the construction industry are presented as follows:

- **Adaptation-oriented:** The industry can be more flexible if it accepts uncertainty and enhances its ability to handle disturbances. This approach integrates the factors of collaborative responsibility, long-term strategy, and co-decision (Li et al., 2018). This technique aims to develop strategies to cope with uncertain events. It is similar to resilience and adaptive resilience developed by Nair and Howlett (2016) and Walker et al. (2012). The construction industry can use this approach to create plans that are flexible and can be adjusted to changing conditions arising from the adoption of AVs. This allows the industry to stay ahead of potential risks and remain competitive. Construction organisations can also make better decisions and improve service quality by collaborating among stakeholders with this approach. However, some may argue that this approach is not fool proof. What if the conditions change too rapidly for the organisation to keep up? What if stakeholders do not agree on a course of action? These are valid concerns that should be considered before adopting this approach.
- **Toleration-Oriented:** The approach’s main objective is tolerating risks. Operational decision-makers are in charge of inspiring the industry to perform efficiently in a constantly changing environment in light of the adoption of AVs (Nair & Howlett, 2016).

On the other hand, this approach may not be the most effective. Tolerating risks can lead to more accidents and injuries, which is not ideal for either the industry or the public.

- **Controlled-Oriented:** This strategy is focused on the prevention of future accidents by providing employees with training and knowledge that will empower them to make better decisions. It also emphasises compliance with laws and regulations, as this will help ensure that risks are managed appropriately. Furthermore, by using realistic risk estimations, the organisation can ensure that its risk assessments accurately reflect the current risk level. (Krieger, 2013). A focus on compliance, however, has been argued by some experts to cause more accidents. Organisations often create rules and regulations that are too restrictive when they focus on compliance. Thus, compliance-focused strategies may actually result in more accidents than those that would otherwise occur. Consequently, employees may take shortcuts or take risks that they would not otherwise take.
- **Prevention-oriented:** Decision-makers implementing AVs use this defensive strategy to reduce their associated hazards (Li et al., 2018). Nevertheless, its slow response time makes policy meaningless. As a result, it is important to invest in more rigorous safety measures and driver education to ensure that AVs are used safely and responsibly.
- **No-Response:** The hazards are not addressed by decision-makers due to the low level of knowledge about AVs and their abilities (Walker et al., 2010). Consequently, decision-makers often overlook the potential threats of autonomous vehicles, resulting in inadequate safety policies.

A variety of these five governing approaches can aid decision-makers in selecting the appropriate approach during the implementation phase. Depending on the environment, one approach may be more cost-effective, while another may be more expedient. One approach may also be more sustainable, while another may be more appropriate for a particular environment. Each of the five AV-related governing approaches must be carefully analysed before implementation to maximise AV benefits while minimising risks in the construction sector.

CONCLUSION

It has been shown that AVs offer a wide variety of benefits, including improved safety due to the absence of human error, improved fuel economy, and reduced congestion. Furthermore, it provides a convenient alternative to traditional transportation modes, in addition to providing new employment opportunities in the development and maintenance of automated vehicles and other activities. The purpose of this study was to examine the potential contribution of AVs to the waste reduction goal of lean construction. The contributions were categorised into three groups: Inventory waste, which can benefit from the ability of AVs to offer improved delivery and better tracking; Transportation waste, which can benefit from the increased capacity, enhanced safety, lower emissions, and enhanced coordination offered by AVs; and Waiting time, which can be reduced by improving equipment utilisation, streamline transportation, and improving coordination among activities.

Also, AVs can help LC address environmental concerns. Furthermore, the paper discussed potential strategies for implementing AV technology within the industry. A discussion of five possible scenarios was provided, including adaptation-oriented, tolerance-oriented, control-oriented, prevention-oriented, and no-response scenarios. This study contributes to the knowledge base by providing an analysis of the potential contributions of AVs to LC waste reduction. Additionally, the examined scenarios in this document aimed to enhance the implementation of AVs in the construction industry to support the decision-makers in selecting the most suitable approach during the implementation phase. The practical implications of the study suggest that the construction industry should take a proactive approach to the implementation of AVs. This is especially true in light of the anticipated environmental benefits and cost savings. These conclusions are made based on an exhaustive round of literature review however future research may involve different chains of keywords and different databases.

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