Use of robotics to coordinate health and safety on the construction site

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Abstract

The construction industry has the highest number of accidents compared to other sectors of the economy. Minimising the risk of accidents requires compliance with safety standards and constant monitoring by responsible persons. The use of robots for high-risk work can increase safety and prevent accidents on construction sites. On the other hand, the use of robots can create new health risks. Especially the use of UAVs is therefore highly regulated, whereas this is not the case for legged robots. This paper identifies the challenges and opportunities for coordinating health and safety on construction sites with robots. It is based on a literature analysis that looks at the status of the general area of application of robots and health and safety coordination services. Based on the literature analysis, guided workshops were held with various stakeholders (site managers, health and safety coordinators, German employer's liability insurance association (BG Bau), clients and planners). To validate the results, a quantitative survey was conducted. The interviewees believe that robots can assist them with activities on the construction site or take over some of the activities independently. Challenges identified the interviewees were mainly related to purchase costs, acceptance by construction workers an unclear legal framework. The results show that robots should work autonomously. To create synergies, robots should not only coordinate health and safety, but also carry out target-performance comparisons with the building model, produce daily construction reports with photos and take measurements of the trades.

Keywords – Unmanned Aerial Vehicles (UAV); Legged Robot; Safety and Health Protection; Construction Site; Safety Management

1 Introduction

Statistically, one person dies on a construction site in Germany every three and a half working days [1]. Around 20 % of accidents at work in Germany and the European Union occur in the construction sector [2]. Falls are the main cause of fatal accidents on construction sites [3]. Compared with other sectors of the economy, the construction industry therefore has the highest accident rate and a high sickness rates [3]. Unlike other sectors, the construction industry is characterised by daily changing conditions and responsibilities for those carrying out the work [4]. Daily changes in construction progress create dynamic workplace situations that are particularly hazardous. Frequent changes in personnel, a high proportion of foreign employees on site, time and cost pressure and weather conditions can also lead to additional hazards [5].

In order to prevent accidents, there are various regulations, laws and standards designed to improve occupational safety [6]. In Germany, the Construction Site Ordinance in particular, is designed to improve safety and health protection on construction sites. In addition, building owners are obliged to comply with health and safety measures.

On construction sites where employees of several employers are working, at least one coordinator must be appointed to coordinate health and safety on the construction site [7]. This means that the risk of accidents can be minimised through safety standards and continuous monitoring, such as inspections by a safety and health coordinator. Because of their moderating role, safety and health coordinators must be able to deal with conflict situations, have organisational talent, a high level of social competence and be able to mediate between the parties involved.

As part of his or her duties, the safety and health coordinator is required to carry out regular site inspections during the execution of the work and document and report any defects or malfunctions. They must also influence those carrying out the work to rectify any errors. [8,9] In practice, the resulting regular inspections mean that safety and health coordinator have to travel long distances between individual construction sites.

At the same time, robots are becoming increasingly important for construction sites. There are various forms of robots, such as exoskeletons, 3D printers, unmanned aerial vehicle (UAV), robots, humanoids or stationary robots that can support activities on construction sites. Robots could improve safety on construction sites and preventing accidents, especially by using robots for activities where humans are exposed to a high-risk potential. Figure 1 shows these robots and their main area of application.

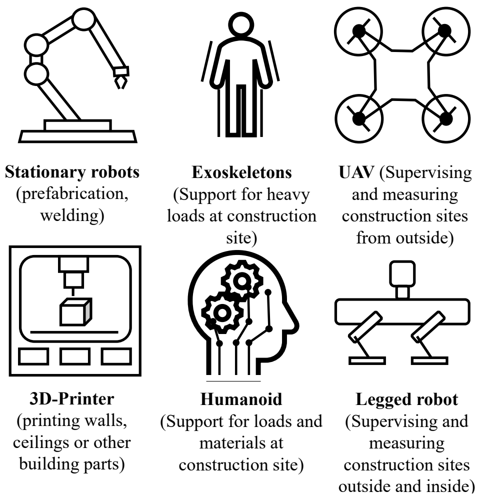

Figure 1: Types of robots on construction sites

Regarding safety managements, especially drones and legged robots could support humans on construction sites by supervising construction sites autonomously and documenting findings with photos or videos. Therefore, this paper examines strategies for coordinating health and safety on construction sites using these two forms of robots by taking practical application, regulatory requirements, and the human-robot-interaction into account.

2 State of the art

The paper is based on a literature analysis that examines the current state of robotic applications on construction sites in general, but also regarding health and safety management services. The keywords "unmanned aerial system / vehicle (UAS / UAV)", "unmanned ground vehicle (UGV)", "building", "construction site", "legged robot", "spot boston dynamics" and "safety" were searched in different variations on scopus, google scholar and springerlink. Figure 2 illustrates the number of publications in the period from 2013 to 2023.

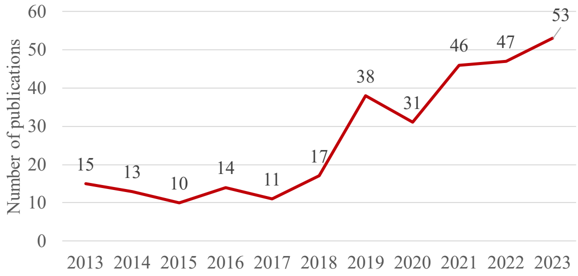

Figure 2: Publications in the period 2013 to 2023

The results show that, particularly in recent years, many papers have been published, that deal with monitoring the construction process, inspecting buildings, and surveying the site using UAVs or legged robots. It can also be seen that the focus of the papers is certainly on the use of UAVs and not legged robots. It should also be noted that the use of robots to coordinate health and safety measures is currently not fully researched. Only few papers deals with the use of UAVs to monitor safety on construction sites by analysing video recordings (e.g. [10]). Several papers also show that there are currently no guidelines for the safe use of robots on construction sites to protect people, especially for legged robots (e.g. [11,12]).

The next sections show the characteristics and possibilities to use legged robots and UAV for safety management on construction sites.

2.1 Legged robot

Legged robots mimic human or animal movements, which means that they can overcome different ground conditions such as stairs or obstacles. In addition, this type of robot requires little to no preparation and setup of the construction site in order to move around. [13]

The stereo camera installed in the legged robot on site can be used to create 3D point clouds for mapping the environment [13]. In addition to the stereo camera, the legged robot can be equipped with other modular configurations, such as panoramic cameras, LiDAR sensors and a with six degrees of freedom robot arm for opening doors [13]. The battery life varies depending on the product. For example, it can be approx. 90 minutes in operation and 180 minutes in standby mode [14].

There is currently a wide range of applications where construction workers could be assisted by a legged robot inside the building, e.g. in construction documentation or quality control. This is currently the main use case and there are several studies in which construction progress has been recorded using a 360° camera [11,15]. These studies are already providing initial insights into the use of legged robots for health and safety measures. In particular, the studies show that the following technical measures apply to the legged robot (1) an illumination level of more than 2 lux is required for operation, (2) glass or transparent objects (e.g. a glass door is difficult for the legged robot to detect), (3) objects less than 30 cm high and objects than 3 cm on the ground are not detected by the legged robot, (4), no use on scaffolding steps and (5) to avoid the risk of collision with the legged robot during operation, people should keep a distance of 2 metres. [11]

A key aspect of using the robot as an aid to health and safety coordinator is that current studies show that applications where the robot frequently encounters people are excluded. In concrete terms, this means that the use of legged robots during working hours could be excluded, or that an operator would need to monitor the legged robot.

2.2 Unmanned aerial vehicles (UAV)

An unmanned aerial vehicle (UAV) is an aircraft without a pilot on board. Thanks to the lift generated by their rotors, UAVs can stay aloft without changing their position or altitude. They are therefore well suited for use on construction sites [16].

A distinction can also be made between remotely piloted and fully automated flying UAVs [17]. Under European law, only remotely piloted UAVs can currently be licensed. Fully automated UAVs do not currently comply with either European law or International Civil Aviation Organisation regulations. [17] In order to operate a UAV in Germany, both national and European legislation must be observed. These include the German Air Traffic Act (LuftVG) and the Easy Access Rules for Unmanned Aircraft Systems apply. [18]

The operation of UAVs may require an operating licence. This depends on the UAV's take-off mass, the flight altitude and flying within visual range. If the flight altitude of the UAV is more than 120 metres or if it is operated in geographical areas, e.g. near hospitals or airports, a risk assessment and approval by the aviation authorities is required for operation. In addition, the pilot will need an EU certificate of competence or an EU remote pilot licence. [19] The flight time of a UAV depends on the take-off weight and the payload, e.g. for cameras or measuring instruments, as well as on wind, weather and flight altitude, and can be between 7 and 30 minutes [17]. UAVs offer the possibility of inspecting buildings or terrain at high altitudes.

Although UAVs can be used efficiently and in a variety of ways outdoors, their use indoors is limited [20]. One of the reasons for this is the difficulty of collision avoidance for UAVs in the air compared to other robots on the ground [21].

The possibility of using UAVs on construction sites has already been investigated in several studies. Inspections of all types of structures, such as bridges or wind turbines, are carried out using UAVs equipped with a camera [17]. Surveys of the terrain using single images and photogrammetric three-dimensional point clouds have also already been carried out [17]. In addition, the use of a UAV to improve site safety has been investigated. The videos recorded by the UAV were analysed using an image processing programme to determine whether the people on the construction site were wearing their personal protective equipment (PPE) [10].

2.3 Conclusions for the integration of robots and safety management

As seen in sections 2.1 and 2.2, the use of legged robots and UAV have different use cases in the construction industry. The resulting technical requirements offer corresponding advantages and disadvantages for use on the construction site. These in turn have an impact on the use of the legged robot and the UAV for the safety management on construction sites. Table 1 shows the advantages and disadvantages of the individual use cases for legged robots and UAVs.

Table 1: Advantages and Disadvantages of the usage of Legged Robots and UAV for safety management on construction sites

Robot	Advantages	Disadvantages
Legged Robot	Is able to climb stairs; Full view of construction site due to 360° camera; Could be used inside buildings	Technical barriers, such as glass or low objects; Is not able to speak or interact with humans; Risk of collision with humans; Must be obeyed by humans
UAV	Could supervise tall buildings; Photos and documentation of high places; Fewer obstacles than on the ground; Larger operating radius	License needed; Partial authorisations required; Could not open doors (not suitable inside buildings; Influence of the weather on operations; Risk of collisions with aircraft; Noise pollution from UAVs

The Table 1 shows, that neither the legged robot nor the UAV fits for all tasks, that need be done by the safety management on construction sites. Especially the human-robot-interaction and the documentation can actually not be done automatically by the robots.

3 Material and methods

Based on the literature analysis (step 1), workshops were initially held with various stakeholders in step 2. These were based on guidelines and aimed to evaluate the current areas of application of robots in health and safety management and requirements for implementing robots for health and safety management in practice. A total of 9 workshops was held. The documentation was done by transcribing the video and audio recordings. The workshops were held via videoconference.

Based on the literature review and the workshops, a quantitative survey was carried out to validate the theses more broadly in step 3. The survey "Strategies for the use of robotics to coordinate health and safety on the construction site" was divided into five subject areas with a total of 14 questions. It was carried out between 29/09/2023 and 23/10/2023 and disseminated through social networks, professional associations (e.g., BG Bau) and health and safety companies. A total of 40 people from different companies and professional associations participated in the survey. Based on the number of members of the German Association of Health and Safety Coordinators, this sample size is sufficient at a confidence level of 80%. The association has 190 members [22].

In step 4 the results of the qualitative and quantitative survey were analysed and discussed by the authors. The aforementioned methodology is shown in Figure 3.

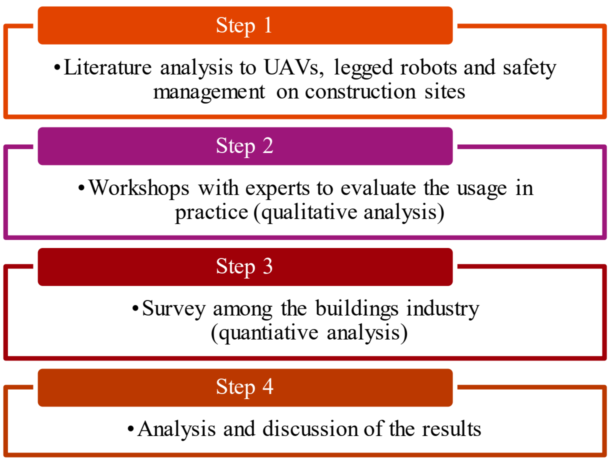

Figure 3: Methodology of this paper

The following sections explain the steps 2-4 more in detail: in section 4.1 the workshops and the results of the workshops (step 2) are described, in section 4.2 the results of the survey (step 3) are shown. The discussion (step 4) is shown in section 5.

4 Integration of robotics in safety management

The following sections describe the results of the workshops and the survey, that aimed to find out possible applications and added values of the integration of robotics in safety construction. The workshops, as a qualitative analysis, were based on the literature reviews. Based on that, the survey was conducted.

4.1 Workshop results

The 9 workshops with up to 3 experts were conducted between 01/08/2023 and 22/09/2023, to evaluate various perspectives on safety management on construction sites, the relevant stakeholders, such as site managers, health and safety coordinators, the German employer's liability insurance association (BG Bau), clients and planners were interviewed in the workshops, whereas respectively 3 participants from BG Bau and safety and health coordinators as well as 5 site managers took part in the workshops.

The workshops showed that the participants have different perceptions of the topic of robotics in safety management. This is because all those involved have a different focus in their work with the construction site and a different level of knowledge about the integration of robotics in safety management. The workshops revealed that none of the interviewees had already fully utilised robotics for safety management on construction sites. However, some workshop participants already had initial ideas on how robotics could be used. However, those who had already dealt intensively with the use of robotics on construction sites in general were also increasingly sceptical about the use of robotics for safety management in particular. This is particularly because of various details, such as driving licences for drone flights or the supervision of robotics, still represent decisive safety aspects for the successful use of robotics on construction sites.

On the other hand, the workshops showed, that the participants could imagine being supported their work by robots. For example, the robot could help with measuring, target/actual comparisons, and construction documentation. However, it was also clear that robots could not replace a visit to the construction site, especially due to

1. lack of human interaction, that is – from the perspective of the workshop participants - a key success factor in ensuring order and safety on the construction site,
2. data protection aspects, such as taking pictures that go beyond the construction site and could capture people on the construction site and
3. the need for a proper documentation of safety risks on the construction site.

All in all, the participants stated, that a robot can complement the work of safety management but cannot completely replace it.

4.2 Survey results

Based on these workshops results, a quantitative survey was conducted. The survey focused on German Safety and Health protection coordinator. The results of the survey are presented in the following three sections.

4.2.1 Situation analysis

The workshops have shown that there is potential to save time, particular by eliminating the need to travel between the office and the construction site. With this in mind, the first question asked was how much time the participants spent travelling between the office and the construction site each day. 40% of respondents indicated that they spend up to 2 hours travelling to and from the office and site in a working day. A further 25% of the respondents stated, that they spend up to 3 hours travelling. The results are shown in Figure 4.

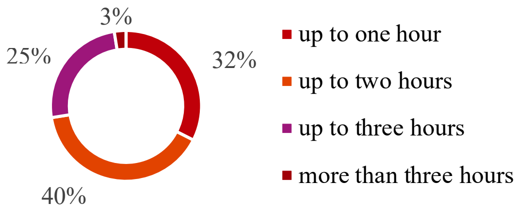

Figure 4: How much time do you spend travelling time between office and site each working day (n=40)

Furthermore, the participants were asked, what work the conduct on the construction site and how they document potential errors. Approx 98% of respondents said that they take photographs of conspicuous features using smartphones or cameras. In contrast, only 15% said that anomalies were recorded using an app on a tablet or smartphone.

These results show, that robots could save time for the construction safety management, by enabling remote working, which saves time by avoiding long journeys.

4.2.2 Robotics in general

Based on that, the participants were asked, if they believe that robots can assist them in their practical work on site in future, so that the time savings could be realised.

Figure 5 shows the results of this question. 75% of the respondents believe, that robots can support them in their daily work on the construction site. 17% of the respondents believe, that robots even could take over part of their daily work on the construction site. Only 8% believe, that robots have no value to their work on the site.

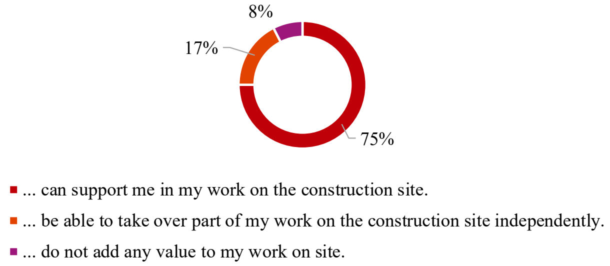

Figure 5: Answers to the question, if a robot could support the work on the construction site (n=40)

In addition to that, the participants were asked, what kind of robot could support their daily work. 62.5% of respondents believe that the use of a UAV can assist them in documenting the construction process.

Although the robots are seen as a possibility for documentation, the interviewees do not assume that this will lead to a reduction in on-site times at the construction site.

The minority (37.5% of all respondents) agrees with the statement that robots can reduce site attendance. On the other hand, 45% partially disagree with this statement and a further 17.5% disagree. This result is shown in Figure 6.

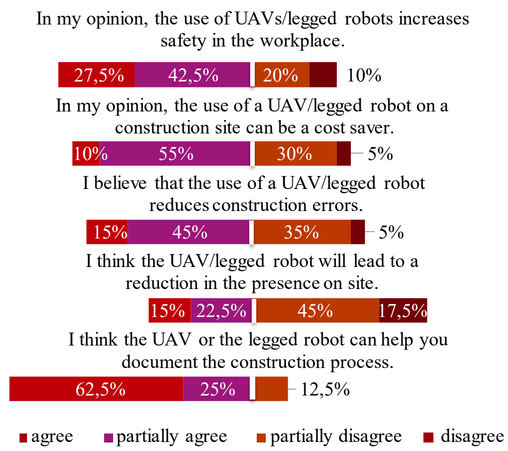

Figure 6: Answers to the question, whether the participants agree or disagree to the following expectations of the robot (n = 40)

On the other hand, Figure 6 also shows, the majority of respondents believe that robotics can improve safety on the construction site in the future. 27.5% of respondents agreed that the use of robots increases work safety on the construction site. A further 42.5% of respondents partially agree with this statement. One advantage is especially seen in the documentation of the construction process and safety aspects (88% agree or partially agree to that statement).

4.2.3 Use of robots - coordination of health and safety protection

According to the respondents, the following characteristics of the robot are a prerequisite for its use in health and safety coordination.

Respondents were divided on the need for the robot to be able to speak independently or interact with other people. Just under 50% see this as a requirement. 43.6% of respondents expect the robot to be able to process data independently. 47.5% expect the robot to be connected to a control centre. 35% expect this to some extent. 52.5% of respondents expect the robot to be able to move around the construction site independently. 72.5% of respondents said that the robot should be able to detect dangerous situations on its own. These results are shown in Figure 7.

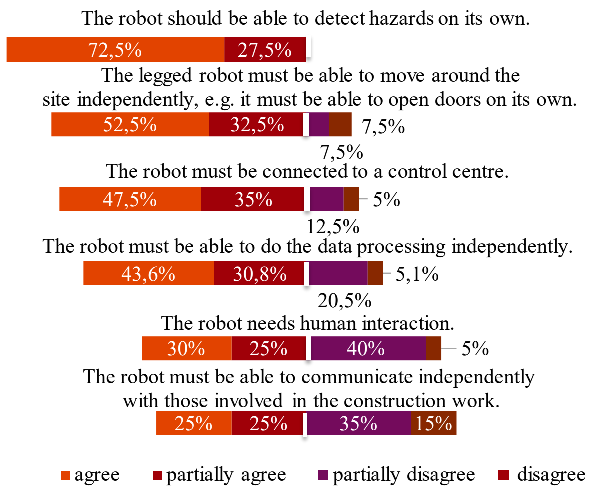

Figure 7: Answers to the question, what characteristic and necessary properties of the robot need to be implemented to support safety management (n=40)

In addition to the requirements on safety robots, the participants were also asked for occurring challenges by using robots for safety management.

Figure 8 shows the results. Especially the acceptance of construction stakeholders is seen as the key challenge (75% of the respondents). This corresponds with the statements from the workshops, which also see a lack of human interaction as a challenge.

In addition to that, the respondents see particular challenges in the cost of acquisition (63%). Furthermore, unclear legal requirements (50%) and privacy policies are seen as challenges. The acceptance of robots as figures of authority is only mentioned by 23% of the participants.

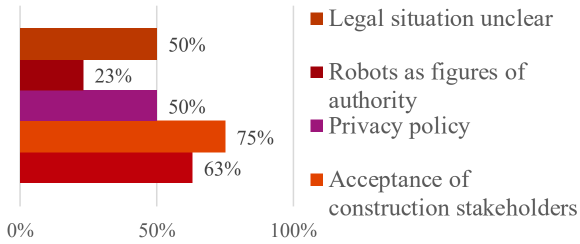

Figure 8: Answers to the question: What challenges do you see in using robots as support for safety management on construction sites (n=40)

Further possible information on the use of robotics in safety management could be entered via a free field at the end of the questionnaire. The participants suggested in that survey, that the robot should provide site security, replacing security guards or camera surveillance. It was also stated that an external service provider should use robots to record data on the construction site and make it available to all those involved in the construction. By doing so, the challenges of costs and flying licences could be avoided.

In addition, one respondent pointed out that the different types of construction sites would also pose different challenges. The use of robots would therefore not be suitable for all construction sites. Lastly, it was also pointed out, that health and safety protection is very difficult. Even as a human health and safety coordinator, it is difficult to instil common sense in the people on a construction site. This would be an impossible task for a robot.

5 Discussion

The results of the study conducted among health and safety coordinators show that the respondents consider the general use of robots on the construction sites to be an added value of supporting their work.

On the one hand, manual safety inspection processes lead to inconsistent, time-consuming and error-prone data collection, what is also supported by ref. [11]. On the other hand, many defects and safety issues can be prevented by real-time monitoring of construction progress and quality control (see also [23]). Robotic data collection can reduce the amount of labour and time required to collect data while improving quality (see also ref. [11]).

However, a closer look at the range of applications for robots, such as coordinating health and safety on the construction site, also reveals that 75% of respondents consider the acceptance of robots by construction workers to be the biggest challenge. The reasons for this became clear in the workshops. A health and safety coordinator needs to be able to deal with conflict situations and have a high level of social skills to mediate between those involved in the construction work. These are qualities that a robot cannot currently demonstrate. However, respondents were divided on whether a robot should be able to speak independently or interact with other people. In addition, a robot equipped with a camera may create a feeling of surveillance among those involved in the construction work. Data protection should therefore not be overlooked in this context.

In addition to data protection, other legal and employment regulations must be observed. National and European laws must be observed when using UAVs. Prior permissions must be obtained from the aviation authorities to fly over buildings of more than 120 metres in height. The location of buildings, e.g. near airports or hospitals, also restricts the use of UAVs and requires additional permits. It can be concluded that the benefits of UAVs should outweigh the effort required to obtain permission and therefore they are not suitable for every construction site. This is also stated by [18] and is reflected in the survey result. For example, 50% of those respondents said that the (unclear) regulatory framework was one of the biggest challenges to the use of UAVs and legged robots.

Some of the requirements that respondents have for robots on construction sites are not currently feasible from a legal perspective. 52.5% of respondents consider it necessary for the robot to be able to carry out its work autonomously on site. UAVs that are automatically programmed and fly without a pilot cannot currently be licensed under European and international aviation law [11].

In contrast to the legal requirements for UAVs, there are currently no legal requirements for the use of legged robots. To date, there are only a few studies looking at the requirements for the safe use of legged robots on construction sites (e.g. [12]). However, human-robot collaboration on construction sites poses a risk. People should therefore keep a distance of 2 metres when operating a legged robot in order to avoid collisions [11].

Another prerequisite for the use of robots in health and safety on the construction sites is the ability to recognise hazards independently. For example, hazard could be caused by steps or pipes lying on the ground. These hazards cannot currently be reliably detected by a legged robot. Recent studies show that the legged robot has difficulty detecting objects less than 30 cm in height. It also fails to detect objects smaller than 3 cm, such as pipes lying on the floor. [11]

Literature and the interviewees also stated that it is difficult to monitor health and safety on the construction sites for robots, because construction sites differ according to the type of work being carried out. For example, there are building sites, civil engineering sites and pipeline construction sites. Each of these types of construction site has different health and safety challenges that the robot has to identify independently.

The cost of the robots is also seen as a challenge by 63% of respondents. Currently, a legged robot costs approx. € 130.000 and a UAV costs approx. €15.000 [24,25]. In the long term, however, costs can be saved through synergy effects. In addition to using the robot purely to coordinate health and safety, the survey showed that it is possible to compare target and actual values with the building model, create daily construction reports with photos and take measurements of trades. There is potential here for a new market segment on the construction site through a company offering centralised visual recording of the construction site using UAVs and legged robots. A company would be contracted to capture site data and make it available to contractors, clients, site managers, architects and health and safety coordinators for downstream processes.

6 Summary

The results show that construction workers generally see the use of robots on construction sites as adding value to their work. However, the use of robots to coordinate health and safety on construction sites is viewed critically. This is due to the need for social skills that robots cannot currently provide. The desired autonomous use is also currently feasible. The autonomous use of UAVs on construction sites is currently not possible under current aviation law. On the other hand, there are no studies on the risks associated with the use of legged robots on construction sites.

The high acquisition costs are also a major challenge, according to the respondents. However, the use of robots on construction sites offers the opportunity to increase efficiency and save time and resources on the construction site. One way of doing this is by bundling synergies. In addition to coordinating occupational safety, the robots will carry out comparisons with the building model, create daily construction reports with photos and take measurements of the trades. Robots could play an important role in the construction industry in the future by supporting those involved in construction in their work or even taking it over completely. Further developments are needed for their successful use. For example, the legal basis for the use of robots on construction sites needs to be reviewed. The risks of human-robot interaction need to be researched and the autonomy of robots needs to be further developed.

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