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.

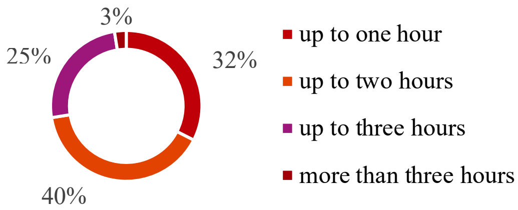

Figure 4: How much time do you spend travelling time between office and site each working day (n=40)

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.

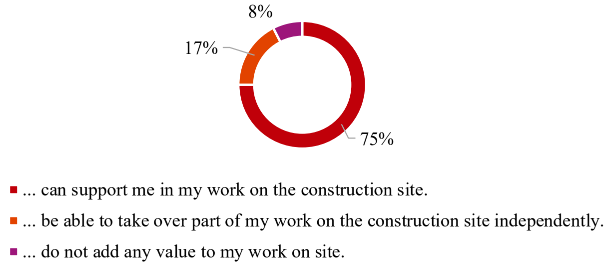

Figure 5: Answers to the question, if a robot could support the work on the construction site (n=40)

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.

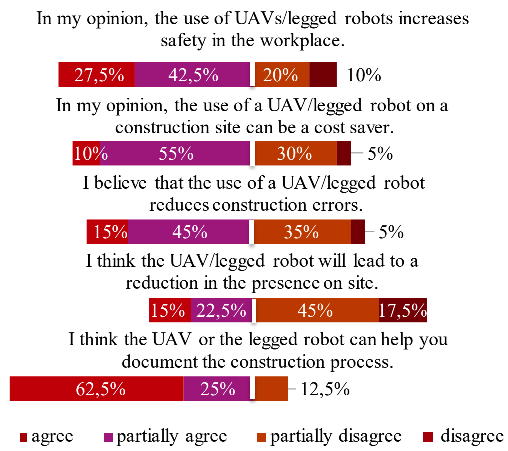

Figure 6: Answers to the question, whether the participants agree or disagree to the following expectations of the robot (n = 40)

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.

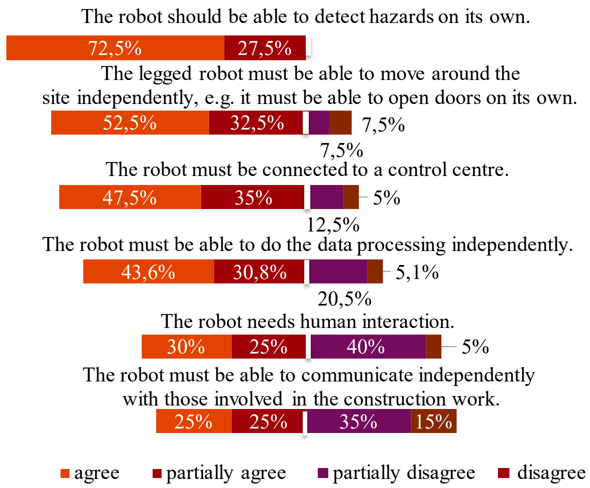

Figure 7: Answers to the question, what characteristic and necessary properties of the robot need to be implemented to support safety management (n=40)

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.

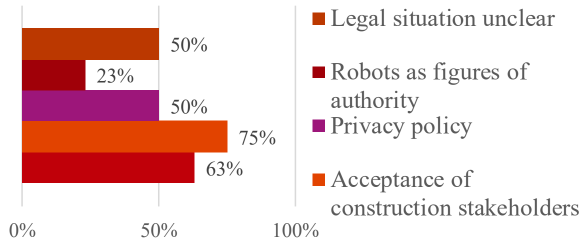

Figure 8: Answers to the question: What challenges do you see in using robots as support for safety management on construction sites (n=40)

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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