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Digital Training and Advanced Learning in Occupational Safety and Health Based on Modern and Affordable Technologies

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Abstract: Occupational safety and health (OSH) is a very important issue for both practical purposes in industry and business due to numerous reasons, so a number of software, educational and industrial solutions are available. In this paper, the cloud-based mobile application for digital training and advanced learning in the field of occupational safety was presented. The proposed framework architecture was based on a novel approach: Node.JS for the server backend and the React Native for the front-end development; while MongoDB was used for implementing the cloud data storage using sensors that are all available on the Android platform. In the development of this application, a number of options were developed (using open-source software) such as the reading of a QR code, usage of built-in sensors within android platforms, reporting, and voice messages. The developed SafeST solution is presented through a real industry example. It emphasizes two main possibilities of the solution, improving OHS reporting and significant empowerment of the students in the OHS field based on the learning-by-doing approach. In this way, the additional engagement (identification, recording and reporting of UA/UC) of OSH managers has been reduced to a minimum, taking into account requested reports from management and authorities, and the continual training of the employees and preparation of the students for future working activities. The system was tested for educational purposes with the initial idea to develop an application for smartphones which could be useful and well adopted among engineering students in the OSH field.

Keywords: mobile app; cloud-based; digital training; advanced learning; occupational safety and health

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1. Introduction

Establishing and managing occupational safety and health (OSH) excellence have become important tasks for modern industries, starting from construction [1], manufacturing [2,3] and aviation [4], to some other industry branches. As the reasons to invest more efforts into the OSH are both ethical and financial [5], there is an increasing trend among companies and academic institutions to pay more attention to their OSH training programs. In industrial practice, it assumes providing high-quality and effective training programs for both workers in the workplace, as well as for safety engineers and managers. Ensuring the effectiveness of safety training is considered to be an important aspect of safety science [6]. As the preventive approach for reaching safety excellence, the authors focused on engineering education have suggested that the training and education about OSH should obtain higher priority and be included in a number of curricula [7]. Moreover, certain number of literature reviews revealed a general lack of high-quality randomized trials in the field of OSH training effectiveness that meet the relevance criteria [8].

The potential impact of information technology on the workspace, and OSH in particular, can be considered from various aspects because Information and Communication

Technologies (ICT) is changing every current employee's career, including education and afterward training as well [9]. From the point of view of educational systems, we note that the change is even more dramatic during the period of shifting to the concept of Industry 4.0 (I4.0). At the core of the I4.0 shift is the employment of new innovative technologies, mainly ICT [10], through the implementation of ICT for digitalization of information and integration of the system in all phases of the product life cycle [11]: cyber-physical systems supported by ICT for monitoring and control of physical systems and processes [12–14]; networking of machines, products and people in the company as well as networking of company and customers and suppliers [15–18]; simulation, modelling and virtualization in design and production processes [19,20]; acquisition of data and big data analysis and their application within cloud systems [21–23].

To date, many different approaches have been employed and assessed for the purpose of improving teaching and learning in the field of OSH. Using virtual reality solutions is one of the assessed approaches, and it has been used in different fields such as construction [24] and chemical plants safety [25], while some authors [26] in their recent studies reported successes of employing virtual reality in some other fields. Some of the virtual reality solutions were even adopted for smartphones [27], concluding that mobile applications are the most preferred learning tools among construction safety learners. A certain number of authors indicated a high value of safety knowledge transfer through mobile virtual reality [28,29]. In addition, different solutions based on augmented reality [30] indicated that the technology was viewed favorably by participants, as the augmentations provided a simple method to learn fall hazard-related information [31]. It is clear that the concept of virtual and augmented reality could be significantly improved using the concept of the Internet of Things (IoT) [32,33]. Some authors [34] proposed wearable and wireless identification-sensing platforms for self-monitoring and hazard avoidance. Although such an approach is suitable for training purposes, some psychological and ethical barriers were reported [35]. Moreover, different software and simulators could also be employed for improving the safety, learning and training in the field of safety [36], including the employment of mobile devices [37]. It has been widely accepted that the development of dedicated software tools for teaching students (during their laboratory work or internships) about their future engagement, has an important role in their education [38]. As the result of these trends, as stated in [39,40] there are increasing demands for ICT-based solutions in OSH training and education.

The research [41] gives an overview of OSH in Industry 4.0 and states that the issue of Unsafe Act and Unsafe Condition (UA and UC) has not been addressed. This research also stated that there are very few articles that deal with incorporation of OSH in the concept of industry 4.0 as well as software solutions that support problems of UA and UC [41,42]. Moreover, this manuscript is an advanced work of our previous work [43]. As a solution, we propose a novel cloud-based mobile application that eases employees to proactively learn and contribute to OSH (focusing UA and UC). The research [44] presented the gap between the practice and safety management requirements. There are misconceptions and misunderstandings on this topic. The same authors stated that a large number of OSH managers, as well as employees, defined a safety management system as additional work, too much paperwork, and differs from real conditions on the shop floor. This could lead to equalization of personal and professional life such as working overtime, and bringing the job to the home [45], and it depends of the individual characteristics and personality of the employees [46,47]. Therefore, a major breakthrough has to be made in the OSH education and training introducing ICT technology. This includes implementation details, possible educational tasks and results of the initial assessment of the proposed solution at our department. The main contribution of this paper is that it improves the learning-by-doing approach which has been side-lined due to lack of time and resources. With the developed SafeST solution, it is possible to improve the training in the field of OSH through continuous implementation, testing of employees' knowledge and improvement of the OSH system as a whole by facilitating the work of OSH managers.

2. Materials and Methods

2.1. Current Practices and Requirements in Training and Learning of OSH

The traditional method of digitalized learning, known as e-learning, assumes using web portals for file sharing and personification of the learning process. In general, the aim of traditional e-learning is to replace books with PCs and websites. However, printed books still remain the major learning resource in classrooms worldwide, while the usage of PCs to access traditional websites is decreasing over the years. In addition, the starting point of our approach is the fact that smartphones (and mobile applications) have taken dominance over PCs in almost all areas, so that mobile devices are becoming major tools that humans use for interacting with the web. Because of these trends, the application of mobile and wearable devices in the learning process needs to be more exploited and accepted.

At the moment, there are numerous software solutions that aim to improve the management of OSH in the workspace, while some of them also include modules and features dedicated to training and learning. However, these packages are dominantly commercial and are not dedicated to being used for educational purposes (Examples of professional cloud-based software dedicated to OSH are: SafetySync (https://www.safetysync.com/, accessed on 16 August 2021), Assignar (https://www.assignar.com/, accessed on 16 August 2021), SiteDocs (https://www.sitedocs.com/, accessed on 16 August 2021), SafetyTek (https://safetytek.ca/, accessed on 16 August 2021). However, there is no platform specialized for the purposes of the OSH education.) in general, so that they show a number of drawbacks once being considered for application as education tools [22]. Moreover, some commercially available solutions demand additional financial resources for implementation and customization. Some recent reports clearly indicated that flexible mobile learning platforms could be a method for improving retention of B.A and M.D. students [48]. One of the reasons is the fact that mobile devices could be used as both measurement devices and data collection devices [49]. Right now, it is also possible to count on the capability of mobile phones serve to provide a high-quality level of service [50]. Additionally, considering the Wi-Fi connection available on each mobile device, other equipment could be easily accessed and used as well (i.e., wearable sensors). However, the present study remains focused on the use of functionalities that are present on typical mobile phones, are more common and much better accepted among the student population [51–53].

2.2. The Proposed Features and Software Architecture

Starting from the considerations given in the previous section, this study proposes a framework that utilizes mobile Android devices with cloud computing for the purpose of OSH training and learning. Particularly, the framework has been designed to provide the following list of features to OSH education:

- Intuitive working environment, ensuring fluent reporting, tracking and analysis of learning progress.
- Easy accessibility, so that students could use the system at university premises, laboratories or during their internship at companies [51].
- Precise and real-time measurements by using Android devices with built-in sensors (Most Android platforms provide an option to access built-in sensors by using the corresponding Android sensor framework, which is the part of android.hardware package and it includes necessary classes and interfaces. Additionally, a number of useful components, i.e., for reading bar codes or access to different Wi-Fi based devices and sensors, could be found as open-source packages (i.e., on portals like the GitHub) which could be used for measuring motion, orientation, and various environmental parameters (temperature and humidity).
- Wi-Fi access for reading inputs from attached or sensors available on the local network and remote devices.

The complete software architecture is developed using well documented open-source technologies (which also reduces the overall costs). As may be noted from Figure 1, the proposed framework architecture was based on using: Node.JS (Node.js is the JavaScript-based framework made on the top of the Google Chrome JavaScript V8 Engine, with the aim to enable execution of JS code outside of browser, thus providing usage of JavaScript for both frontend and backend development.) for the server backend and the React Native (The React introduced the concept of using the Virtual DOM and Diffing algorithm, which more efficiently handle dynamical changes of HTML content compared to the traditional DOM re-rendering. React Native represents adaptation of web JavaScript technology to work on the top of native frameworks of various mobile platforms.) for the front-end development; while MongoDB was used for implementation the cloud data storage. In addition for the used technologies, we emphasize that one could also use alternative technologies for mobile development, based on Java or Kotlin programming languages.

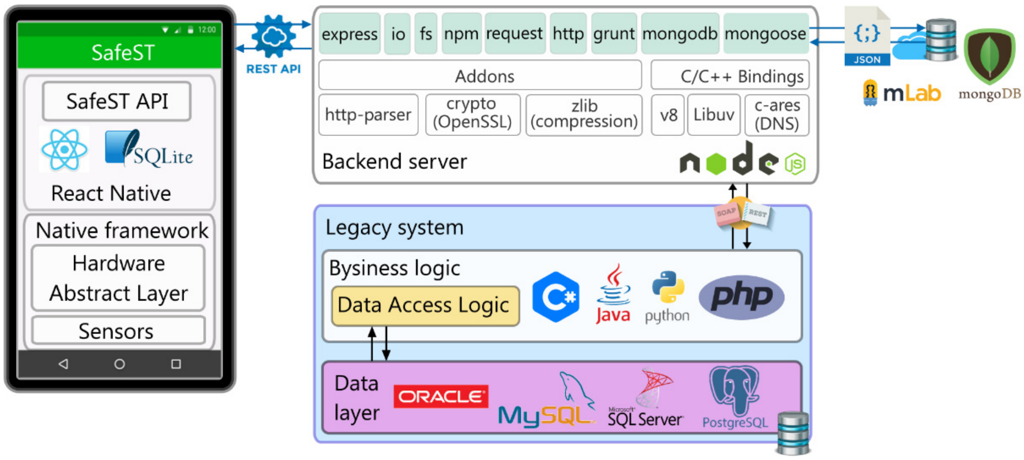

Figure 1. Software architecture of the system.

The assumption was that, in general, potential users have an already existing ICT system (Legacy system) that has been implemented using some alternative technologies (at our faculty, the existing ICT learning system has been implemented using PHP and MySQL database). Since features of the SafeST backend were released as RESTful web services, an adaptation of the proposed solution on the top of the legacy system could be done easily using rest/soap web services. Moreover, the local SQLite database was used on the client-side for storing basic data about users (identification parameters, parameters for system access) as well as results of some measurements before the synchronization with the central system is made. In general, the Android sensor framework supports a wide range of sensors for measuring environment parameters (motion detection and rotation detection, monitoring air temperatures, rotation detection, air pressure changes, monitoring dewpoint, absolute, and relative humidity) [54]. Through these sensors, dedicated software incorporates functionalities of external devices or sensors connected to peripheral I/O.

Android is supported by different sensors [54], which could be divided into two categories: (a) Hardware-based—They derive data by direct measurement of the specific environmental properties, such as acceleration, geomagnetic field strength, or angular change; (b) Software-based (virtual sensors or synthetic sensors)—they are not physical devices, but they mimic hardware-based sensors. For the purpose of the proposed application, we used the above-mentioned sensors which are all available at Android 4.0 API Level 14 (most of them are also present in Android 2.3 API Level 9, excluding temperature and humidity sensors).

2.3. *Workflow and Functionalities of the React Native Application*

The proposed application SafeST improves user exercise during the OSH training of employees and, with the special focus on detection, storage and analysis of UA and UC, as well as the Job safety analysis and Hazard Analysis and Risk Assessment.

The SafeST enables the following list of functionalities (Figure 2):

- Localization of unsafe conditions and unsafe acts through the intuitive graphical user interface (GUI). A precise location (Model zone) of UA and/or UC could be detected:
  - Manually by selecting an area from the drop-down menu with predefined sectors, or
  - Automatically by using the built-in sensors for a precise definition of the location.
- Identification of different types of UA and UC. Students could select specific fields from the drop-down menu with predefined categories of unsafe conditions and unsafe acts. The list of UA/UC for a specific company or training example could differ according to industrial standards and specific characteristics of the working environment. However, in both cases, one has to provide information about spotted risks through the interaction with the GUI component.
  - In this step, potential hazards and risks could be connected to the specific component identified by the QR bar code. The software has the option for reading bar codes depicted in Figure 2. The QR code enables linking physical objects in the real world with digital content and assets online (in this case 3-D models, standards, directives, slideshows). This is an approach in which professors can attach all sorts of additional information to the equipment to assists in the use and improvement of workplace safety.
  - The second component is using the built-in sensors for changes in the ambient environment near a device/component, temperature sensor and humidity, positioning sensor as well as open options to get data from other Wi-Fi sensors.
- Risk assessment (risk level) of the spotted UA/UC. This represents an initial-subjective assessment performed by a student on the site, while the final grading and evaluation of the task will be performed later by a professor. If a professor notices that his/her student misunderstood the safety issue, he/she could provide for them additional training or instructions.
- Description, which enables students to provide an opinion about UC/AC in the form of text or voice message. Students determine the best way to mitigate the risks of each of the hazards.

GUIs are developed to be intuitive, scalable and with responsive design. All collected data were stored in the NoSQL MongoDB on the cloud. Since the SafeST has its local storage, users are able to save their collected data and submit them later—in situations when there is no available connection to the central server. As mentioned above, all data transfer was performed in the form of JSON reports. Having data in the form of reports enables professors' easy access to the previously submitted reports, to inspect and evaluate them. It also enables students to search and learn from both collected examples and generated case scenarios.

The SafeST has two types of users: students and professors. Briefly, students can use the previously described list of functionalities for collecting and viewing reports, while professors can additionally upload new cases as well as manage collected reports. A detailed description of features available for professors are described in the following list:

- Task definition. A task could be defined as a real-life problem, a pre-defined showcase (with assigned risks and hazards), or an educational task that needs to be done within an appropriate model zone in the company. In the first case, we assume that students work in the real-life environment and can use location sensors as well as the other ones as a part of the application, while in the second case, students receive and upload the problem that they need to identify, describe and report.
- Collection, correction, grading and storage of tasks delegated to students. Professors could form the list of the tasks that will be assigned to the students in order to be able to correct and grade the same.

- Reporting about resolved tasks or asking for additional instructions the students and professors could have consultations. Professors do not have to wait until the end of tasks' completion, but they could provide additional information in real time.

Figure 2. Basic dialogs of the Android SafeST application. From left to right: SafeST main menu, Localization menu, UA/UC identification menu and Description menu.

3. Results and Discussion

The purpose of this section is to assess the SafeST's capacity to release a concrete OSH educational task. It begins with the description of educational requirements and aims that need to be met. It is completed with the description of a representative OSH use case and the discussion of the experience gained during the process.

3.1. Description of Educational Task and Its Purpose in Learning OSH

Hazard Analysis and Risk Assessment is a technique that aids in identifying hazards associated with a particular job, operation, or task before they occur. There are two key issues that need to be addressed during the recording of UA and UC, and their further processing: the first one is proper UA/UC identification and the second is subjective evaluation of the risk level with the definition of priorities in the correction already identified UA/UC. The most important problem is the inadequate identification of UA/UC. Workers, trainees and students in the recording of UA and UC usually use the most basic tools because they are focused on the number and not on the quality of the records. During the identification of UA/UC, a number of errors emerge, mostly in reporting the large number of UA/UC without a distinguished difference between them.

The practice has been witnessing that between 40–65% of recorded potential UA/UC is not possible to categorize and as a result, it takes a lot of time to make an analysis of the recorded data. Identification of UA/UC is very important because reducing the number of injuries is pointless without this step.

Considering the importance of UA/UC, and using the developed application, it is possible to define a number of educational tasks. Education or training could be performed inside the selected model zone in the organizational unit. Students start with a scan of a QR code (use of this code also enables definition of personalized tasks for each student or trainee) in the specific educational zone, selecting location and additional documentation. The general task is to make identification, recording and reporting of UA/UC. The task is divided into the following steps:

- The first step: Identification of potential UA/UC. Students need to make the correct identification of potential UA/UC and to forward the information to the system. The application evaluates students' input and approves or disapproves selected categories of pre-existed UA/UC. One of the key parameters of the success of UA/UC identification is the acceptance rate of successfully identified UA/UC out of a total number of requests. In this step, students could record the exact position of the object (for example) or location using a positioning sensor from SafeST.
- The second step: Assess the risk and provide a risk level rating to each hazard. According to the defined task in the model zone, students access the level of the risk and define priority level. In this step, students evaluate possible consequences regarding the likelihood of its occurrence and assess the risk level of identified UA/UC. In addition, students could use the system for positioning, and sensors for measurement of vibration, temperature as well as some other parameters (using the options from a SafeST). Students also have the option to have direct communication with professor or to use theoretical material and other information provided by QR code.
- The third step: Reduce risks. After successful identification of UA/UC and risk assessment, and gathered data from sensors if applicable, students prepare a report suggesting the list of preventive measures for implementation in order to reduce risks. The prepared report will be sent to the professor for evaluation and to the database for storage for future use.
- The fourth step: Learning from examples. The system contains previously made reports so students could browse the system by risk or by UA/UC category in order to find documented reports with preventive measures. In addition, the system keeps all previous versions so students could save their reports and make additional versions or corrections later on.
- The fifth step: Verify effectiveness. If the level of the residual risk is acceptable, then the risk assessment process is complete.

3.2. Description of Educational Task and Its Purpose in Learning OSH

The use case was designed to demonstrate OSH learning through solving real-industry tasks (for example, during an internship or faculty lab). Students were asked to: (1) identify UA and/or UC, (2) perform a risk assessment and (3) provide measures for the risk reduction. By learning how to distinguish between UA and UC, students will proactively learn to distinguish and recognize industry challenges. The whole process is controlled and mentored by professors, who have full access to change, to adopt and to supplement archived examples, as well as to evaluate students' reports. The evaluation assumes reviewing and grading students' tasks (positive or negative). Before it is used, the SafeST application was preconfigured and adjusted—which includes importation of model zones and units that exist in the observed company. Examples of an assessment are shown in Figure 3.

In the considered case, a student had selected Model zone 1 (metal parts). As may be seen in Figure 3a, this model zone envelops a serial production of metal parts by using CNC lathes (CNC1, CNC2 and CNC3). Moreover, the working environments also include pedestrian and forklift pathways. In our case, the student noticed one UA related to CNC2 (Figure 3a). After definition of the model zone is made, the student needs to identify noticed UA/UC (Figure 3b). The example in Figure 3 shows UA/UC that belongs to the category of ergonomic hazards—particularly, it reports the inadequate body posture for a long time during work activities. Afterward, it is possible to capture a picture (Figure 3c) of the identified UA that will become an integral part of the report. After the picture is captured, the student writes his/her observations in a text-box form during the work (Figure 3d). This could be a subjective opinion and/or observation of the identified employee's working activity. In our example, the student described how much time an employee spent in the observed position (which emphasizes the severity of the identified UA).

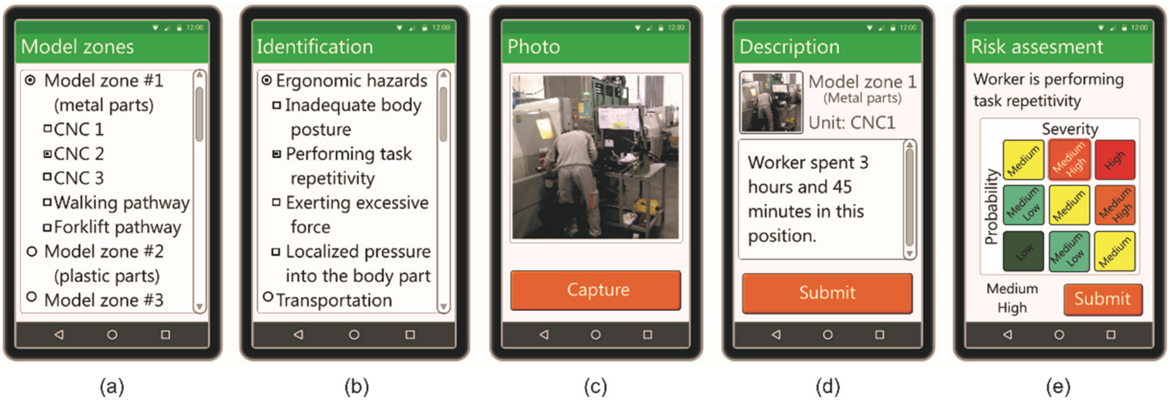

Figure 3. Model zone and usage of SafeST application, (**a**) Model zones, (**b**) Identification, (**c**) Photo, (**d**) Description, (**e**) Risk assessment.

Finally, the student assigns the risk level to UA, based on his/her own knowledge and experience (Figure 3e). There is the 3 × 3 matrix with five risk levels, which enables students to choose the estimated risk level for the identified UA (inadequate body posture).

After finalizing all steps from Figure 3, the student can proceed to the next UA/UC (i.e., oil spill in the category of the slips/trips/falls hazards).

After finalization of all the steps shown in Figure 4, the student can proceed to the next UA/UC (i.e., oil spill in the category of the hazards such as slips/trips/falls—Figure 4 or forklift pathway—Figure 5). These examples depict a number of practical examples that could be solved and used in safety education. It is important to emphasize that all real-industry reports collected by students could be potentially used for the OSH education—after the professor approves and assigns the same as appropriate educational material. In this way, students could be encouraged or recognized for their contribution to the learning materials database. In addition, any hazard which was initially omitted to be identified could afterwards be reported by another student. Consequently, the student will be informed about the update and could benefit from the continuous SafeST database improvements. It is also important to emphasize that system has great potential and has already been used in real-life industrial systems, for both purposes: training and reporting.

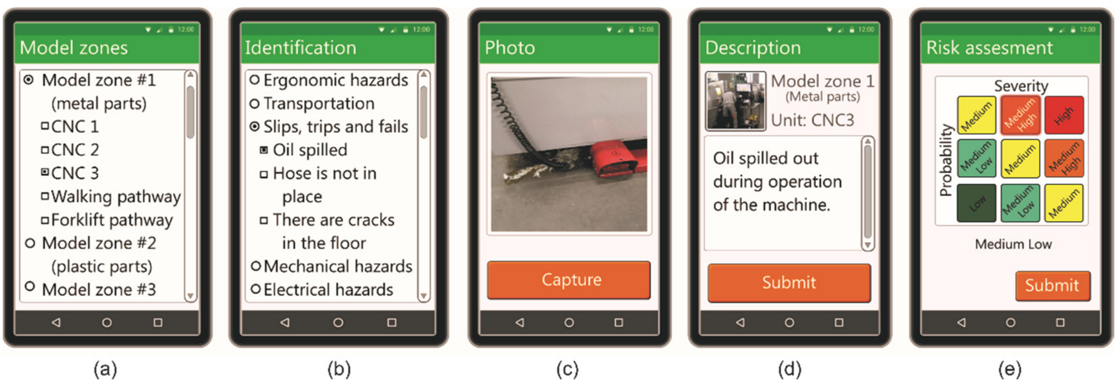

Figure 4. Example of oil spill in the category of the hazards such as slips/trips/falls, (**a**) Model zones, (**b**) Identification, (**c**) Photo, (**d**) Description, (**e**) Risk assessment.

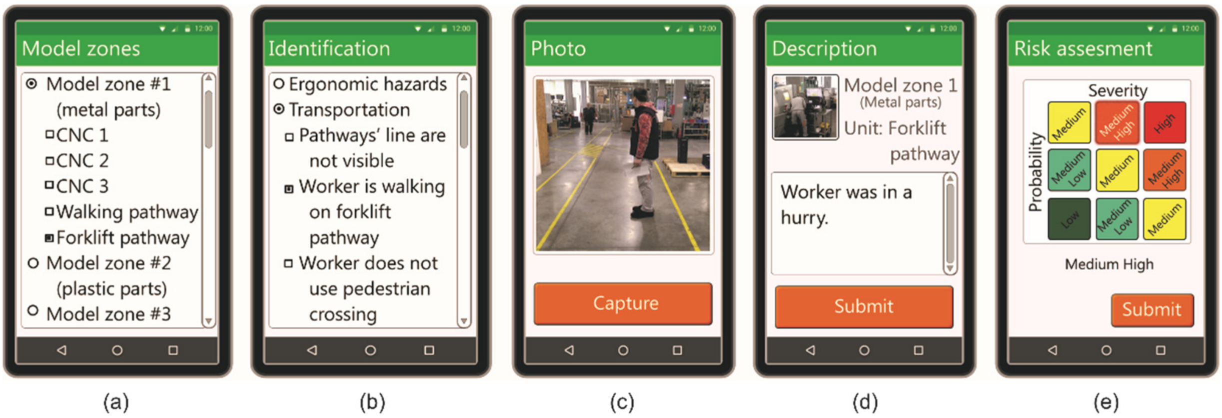

Figure 5. Example of forklift pathway, (**a**) Model zones, (**b**) Identification, (**c**) Photo, (**d**) Description, (**e**) Risk assessment.

It could also be noticed (from Figures 3–5) that the system enables a high level of usability heuristics, providing good visibility of the system status, a good match between system presentation and the real world (actually one of the options is real-life examples), good user control, consistency of presentation, flexibility and efficiency, minimalistic design (that is very important for mobile solutions). At this stage (as future development), it is necessary to make an effort to include help and documentation as well as to provide a higher level of error protection including recovering from errors.

A short survey was conducted after the implementation of the SafeST in students teaching and learning. The target group were the students attending course Occupational Safety and Health at Work at master level. The total number of students (12) who participated in testing was low at that point. Therefore, the results of the testing were informative and taken into account for further development of the application. They were asked to fill out a questionnaire. In the first part, students were asked general questions about their willingness to the adoption of ICT technologies in everyday teaching activities. Additionally, the majority of the students have not approved usage of body sensors—they explained that they do not feel comfortable with sensors. Moreover, they consider mobile phones as something they use every day; they found it more appropriate to use their phones to measure the data or for some other different educational purposes. This approved the initial idea that application development for smartphones could be useful and well adopted among engineering students in the OSH field. In the second part, the aim was to evaluate the developed solution and its corresponding options. It could be noticed that all options were highly graded, starting from using the phones as QR readers, the instruments for tagging hazards in educational/model zones, measurement and reporting. Moreover, they highly graded the option for sending reports using smartphones. Insufficient knowledge about unsafe acts and unsafe conditions, as well as why it is necessary to collect this type of data was the biggest issue during the testing.

This architecture as well as the presented solution is open for a number of improvements and extensions and future developments:

1. First of all, one of the limitations is the number of sensors used in this solution. In this solution, we employed a limited number of built-in Android sensors. Moreover, the other built-in sensors could be used as well as Wi-Fi sensors (or even combining sensors and systems such as Arduino, Raspberry Pi).
2. The system could be extended with the use of wearable sensors. One of the possible improvements is to provide wearable sensors (on the worker or students) that will gather data and the same to the mobile application.
3. The application could be improved in order to "recognize" specific situations and risks providing the possible solutions or providing the option that the system learns using solved examples and recognize possible patterns.

4. System could be modified and adapted to the specific industrial sector (construction industry) or used for specific business and industrial purposes.
5. In educational and training field application, there is a limited number of defined templates. A number of templates could be increased as well as the system could be interconnected with other learning platforms (using QR code reader the user could be forwarded to different online resources or lessons in the LMS system).

4. Conclusions

Work-related research, education, and training in the field has not been widely recognized in many developing countries (DCs) as the most important factor for sustainable workplace improvement [55,56]. On the other hand, the use of modern technologies and approaches could provide new means of training and education.

The presented SafeST application solution differs from the classic e-learning platforms in a number of aspects. First of all, this is not a Learning Management System (LMS) (it is real-life learning and reporting platform, where reports and results could be exported to different LMS), the suggested platform has two different options to be used as a teaching (learning) platform as well to be used in the real-life system. The presented platform enables the identification and record of potential UA/UC. The users also have two options: to use predefined problems or to go into the real-life environment, record potential UA/UC and measure a set of parameters (and send these reports to the cloud system).

SafeST application was developed as android application for smartphones and it provides two general sets of functionalities: students' and professors' parts of application. The suggested solution has the following functional characteristics for students: login to specific profile with a database of examples, usage of the QR code reader, UA/UC identification, measurement of different parameters using built-in sensors, development of reports for UA/UC condition, taking evidence of the UA/UC in form of pictures, writing observation based on the current state, and performing communication with and getting feedback from professors. Professors could give specific assignment to students (real life examples from industrial model zones and laboratory training zones, or examples from database), correcting and grading assignments based on the reports generated. Using this solution, it is possible to achieve different educational goals in the OSH field, as follows: better awareness, better understanding, hands-on training, and offering opportunities to personalize working assignments for students. Particularly, in this paper, the real industry example (automotive industry) is used to present current possibilities of the SafeST application.

The complete application is developed using open-source environment, combining different concepts in development of front end of application as well as back end additional characteristic is storage data in the MongoDB. The general novelty is employing the computing power that each student has got in his pocket. Smart phone packs have interesting hardware, with a certain number of options, such as: Gyro sensors, barometers, and geomagnetic sensors (available sensors differ per model).

This system presents a starting point for improvement in different fields, such as software (elements of the expert system), hardware components (sensors), and implementations (industry-specific field) or in the educational and training field. The system has an open, flexible structure and therefore it is very easy to apply improvements in any direction.

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