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Competencies of Industrial Engineers for Implementing Augmented Reality Metadata Systems

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Abstract: The paper focuses on the use of augmented reality (AR) by industrial engineers, especially for determining the necessary competencies required for its use. Industrial engineers are not inherently programmers. Nevertheless, augmented reality is a modern trend in their field, especially in relation to the concept of Industry 4.0 and industry in general, where it has a higher potential than virtual reality. In the first part of this paper, we placed augmented reality and the competencies required for its use in the context of industrial engineering. Subsequently, we described our own methods of implementing an augmented reality industrial metadata visualization system, namely Help Lightning Fieldbit and Unity 3D, using the Vuforia extension. We chose the metadata used in the methods with regard to their environmental potential. In this part of the paper, we also described the chosen and applied testing methodology using a questionnaire survey. Subsequently, we described the results from the questionnaire surveys of both these approaches of implementing augmented reality methods. Finally, we evaluated the results and compared them with each other and with results from other authors. As the results show, the most important competencies for creating the described AR environments are analytical competencies. We draw conclusions from the collected data regarding the necessary competencies for the creation of AR scenes using these methods and their deployment in industry, including an outline for further research.

Keywords: augmented reality; human–computer interface; competencies; production data; skills; Industry 4.0; industrial engineering

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1. Introduction

The concept of augmented reality (AR), although not as widespread as virtual reality (VR), is coming to the fore in the context of new disruptive technologies. It is a technology that makes it possible to project digital 3D artifacts onto the real world [1].

Virtual reality is a technology that has already been mastered and is used by the majority of its potential beneficiaries. It can be expected that augmented reality technology is yet to be used or expanded by potential beneficiaries. The global augmented reality market accounted for USD 17.14 billion in 2020 and is expected to reach USD 128 billion by 2028, growing at a CAGR of 29% from 2021 to 2028 [2].

In industrial and business applications, augmented reality has fundamentally greater potential than virtual reality [3,4]. The first visions of practical use of AR can be dated back to 1992 at Boeing, when Boeing researchers published one of the first papers on the topic, dealing with a system for visualizing riveting using a semi-transparent display [5].

One of the first definitions of AR was formulated by Ronald T. Azuma [1], who defined augmented reality as systems having the following three properties:

- They combine real and virtual;
- They are interactive in real-time; and

– They are registered in 3D.

This definition is not tied to a specific technology and does sufficiently define the concept of augmented reality; moreover, it does not consider the embedding of various simple 2D information as augmented reality. This definition only allows augmented reality elements as those that are sufficiently "embedded" in the scene (typically 3D objects).

In the literature we find several approaches to place AR and VR in the context of the so-called virtual continuum, which schematically defines the relationship between reality and virtuality. The term XR (mixed reality) is then anything that is neither a virtual environment nor a real environment but stands between them [6,7]. However, it is preferable to look at XR from the perspective of the level of local presence where, on the one hand, stands the so-called assisted reality (stable virtual content) and, on the other hand, XR, which in this case is seen as "enhanced AR" whereby physical objects can interact with virtual objects [8].

AR, therefore, brings an interesting, modern, and one can say game-changing technology to the industry [9,10]. A major obstacle for mass deployment is currently the lack of AR mature hardware. In the case of truly automated manufacturing, it can be said that many processes will be replaced by robots, but in standard manufacturing, fast information transfer (ideally through easy visualization) is irreplaceable. Even in the case of fully robotic production, however, AR can be considered for control processes. AR, therefore, offers a new option for the human–computer interface. For this reason, user acceptance of this technology should also be discussed.

In our previous research [11] on immersive technologies, we identified that the main problem in the acceptance of immersive technologies is so-called "cybersickness". This phenomenon was described as early as 1993 [12], where many symptoms were described (e.g., nausea, stomach awareness, sweating, increased salivation, vertigo, dizziness, etc.,) and a general questionnaire was constructed, the validity of which has been confirmed by recent studies using newer hardware (e.g., [13] or [14]). Another problem we identified may be the generally impaired orientation of some users, especially those without experience in IT (or immersive technologies) [11,15].

If the focus is on user acceptance in the context of AR in industry, it can be concluded that numerous studies in different industrial application areas with prototypes of AR-based systems show that user acceptance is increasingly considered a crucial factor for the success of AR systems. The selection of relevant factors is closely related to the corresponding use case. A generally applicable procedure does not yet exist [16]. The long-term risks of AR use should also be kept in mind. Observation from a study [17], which looked at the long-term effect of wearable AR (here each proband wore AR glasses for 3 months), showed that externalization of spatial navigation to the technological device (GPS in AR glasses) can decrease the functional coupling between the hippocampus and associated brain regions.

According to multiple sources (e.g., [9,18,19]), the main directions of industrial uses of augmented reality can be divided as follows.

- Collision analysis: by combining the real world—the production line—and the virtual model, it is possible to quickly check from all sides whether partial collisions (typically within production) will occur.
- Concept planning: using AR, various 3D sub-models of the line can be projected onto them, but it is also possible to plan sub-workplaces [20] and/or offices.
- Deviation comparison: A virtual part (i.e., actual CAD data) is projected onto the real part. It is, consequently, possible to compare how the real part corresponds to the designer's idea within the sub-parameters of the part [21].
- Part verification: this is either a visual inspection of the part (see the previous section) or an AR verification of the assembly.
- Workshop planning: study [18] identifies the potential of AR in layout planning
- Virtual instructions and maintenance: this is one of the most researched applications of AR in the industry (e. g.. [22,23]). These are typically either used directly in production or within training applications [24]. Tutorials can be linked to phone calls as remote

support [25] or [26] production and documentation, and are especially easy to trace. The principle of pick-by-vision can be used.

- Display of metadata: a display of extended information directly within the production line (see below).
- AR Navigation: calculation of the exact outdoor/indoor position [27–30] with which the AR visualization of loading and unloading is related.

AR devices can be divided according to the location of the display [31].

- Head mounted displays (HMDs), which are worn on the user's head. (e.g., [32])
- Hand held displays (HHDs), which are held in the user's hand. The most common examples are mobile phones and tablets. (e.g., [33])
- Spatial displays, which are placed in space. These include projection screens placed in space or mapped images on objects (in situ projection).

A key requirement for augmented reality is that it should be mobile. It is clear that mobile phones are currently the most widely used equipment for AR. It is a massively distributed piece of hardware, and given that there are also several apps readily available to everyone; the public is well acquainted with the basic capabilities of AR. However, the truth remains that a more powerful mobile phone or tablet is often required to implement an industrial AR application. A major barrier to implementing apps in an industrial environment is the requirement for hands-free working, i.e., implementing AR using a headset. Unfortunately, there is currently no optimal hardware. Although the number of studies conducted with the current high-end see-through display MS HoloLens is growing significantly, even this hardware is still not ready for everyday use in the industry [34].

In this article, we will focus on the implementation of one industrial application and the display of metadata directly on machines. This application appears to be very useful as a fast and practical mediator within the human–computer interface. Data from sub-sensors can provide the user with information from various sensors, e.g., temperature, machine speed, vibration diagnostics (e.g., [35]), or even particular data on energy consumption or savings. Such a visualization system can be part of a larger system that, for example, uses AI algorithms to manage energy consumption or even part of a complex predictive maintenance system, or other systems using AI [36,37]. Such metadata is usually based on enterprise Big data. The links between signal processing, machine learning, neural networks, data mining, and augmented reality and their benefits have been demonstrated in [38]. The review article [39] deals with the display of such AR data in the construction industry within the framework of the building information modelling (BIM) system. The authors see the benefits of AR for BIM as improving decision-making, collaboration and communication, increasing productivity, providing additional resources for problem-solving, and reducing waste, defects, and rework in construction. Several studies (e.g., [40]) have addressed the optimization of AR visualization—this paper will use already-developed tools and architectures to implement a metadata visualization system.

Due to the lack of mature hardware for AR implementation using the headset display, the handheld display method was chosen.

In this paper, we explore two specific novel methods for developing an AR environment for displaying enterprise metadata. The measurement of the difficulty of using these methods (see the Methods section) is directed at the expert user who is also an industrial engineer. We will look for core competencies relevant to the implementation of both methods and, for this reason, the terms "industrial engineering" and "industrial engineer" need to be defined. Subsequently, a categorization of the competencies can be made.

Industrial engineering (hereafter referred to as "IE") is, by one definition, a leading discipline concerned with the design, implementation, and improvement of integrated systems that are socio-technical in nature and integrate people, information, machines, energy, materials, and processes throughout the life cycle of a product, service, or program. [41].

Another definition describes IE as a multidisciplinary field addressing the current needs of companies in the field of modern industrial management, combining technical knowledge of engineering disciplines with knowledge of business management and, on their basis, combining, rationalizing, optimizing, and streamlining production and non-production processes. It systematically deals with the design, planning, implementation, and improvement of industrial processes and implementations [42].

Kosky et al. [43] say that industrial engineering refers to the production of any economic goods within an economy. They then do not define industrial engineering as a whole but divide it into categories:

- Production and quality control;
- Engineering methods;
- Simulation analysis and operations research;
- Ergonomics; and
- Material handling.

If we look at the industrial engineer and the requirements placed on them, the Czech National Occupational Framework defines an industrial engineer as a worker who plans, designs, manages, and implements complex integrated production and service delivery systems, ensures the performance and reliability of systems, manages costs, improves processes, increases labor productivity and production efficiency. Among the list of activities of an industrial engineer, there is also education and training of employees, for example, in process improvement and workshop facilitation. Computer competence is listed as the most important of the general skills [44].

Ivan Mašín and Milan Vytlačil define an industrial engineer as a person who alerts other engineering professionals that there is such a thing as business reality, helping to bridge the gap between line workers and managers. The industrial engineer knows that buying an expensive machine does not necessarily mean a substantial increase in productivity; they must have insight and always consider the overall solution, i.e., they are always aware of the context [41]. After defining industrial engineering and industrial engineers, we can focus on competencies and their categorization. Although it has not been possible to find definitions of competencies aimed specifically at industrial engineers, it is possible to take inspiration from authors and publications focusing on competencies in general and IT competencies in general.

Even if industrial engineers are not specialist programmers, they are often involved in projects that use virtual and augmented reality to improve business processes, which can and often do cover everything from recruitment, employee training, improving production processes, and information flows within and between collaborating companies or in the supply chain to, for example, workplace safety and security improvements. In most of these cases, the possibilities of virtual and augmented reality can be used nowadays, and modern companies are following this path [45]. Therefore, even if industrial engineers are not specialists in programming, 3D graphics, image processing, etc., they need to have basic knowledge and skills and be able to have a basic understanding of virtual and augmented reality, their implementation, and their use [46]. In their professional life, it is, therefore, advisable that they are able to choose the appropriate technology to solve their problem (e.g., focusing on the scope, degree of expertise required, speed of development, etc.). Therefore, it is necessary that they have at least a basic overview and basic IT competencies, as purely industrial engineering competencies (e.g., JIT, SMED, Kanban, and generally PUSH/PULL manufacturing principles, etc.,) are not sufficient [47,48].

According to [49], there are three areas of important competence for IT/programmers.

- Business Competence: competencies related to the market, customers, competitors, economy, social environment, etc.
- Technical/Professional competence: competencies specific to the job/task, e.g., specific technical knowledge/skills such as knowledge of programming, 3D modeling, etc.
- Social/Human competence: competencies needed to cooperate with others, e.g., teamwork, communication, etc.

These groups of competencies can be represented by a competence triangle. The triangle accents the importance of interconnection among the three areas of important competences [49]. These three types of competences have an impact on individual capacities.

The authors of the paper [50] focus directly on defining the general competencies of software professionals using the Kano model [51] and the competency framework for software engineers [52], and propose their own framework, which they call the unified competence gate for software professionals. Within this proposed framework, the authors address not only competencies but also the length of work experience (in years).

Another approach that was examined is mentioned by the authors of the paper [53]. They are using digital skills as the general competencies for digital technologies based on the digital economy and society index. The digital skills mentioned in the paper are too general for the purpose of the presented paper.

In their case study, the authors [54] used the framework proposed by [55] and divided the types of engineering companies into eight categories, A (large forklift and earthmoving machines provider) to H (large CNC machines manufacturer) and, for each category, they determined technical, methodological, social, and personal competencies.

In [56], there are claims that there is a gap or competency mismatch between computer science graduates/IT graduates with the competencies needed by an industry. Their work defines forty-seven competencies divided into three groups: hard skills, soft skills, and business skills. The study involved fifty-eight participants divided into three groups: a lecturer, a professional in the industry, especially in IT, and a group of those involved in both professions. We can see that the competencies of programmers according to industry users, professionals, and lecturers are not very different, and that means that the learning objectives of programming in higher education are in line with what is desired by the industry as a graduate user. In addition to hard skills and soft skills, a programmer also currently needs to have business skills [56].

In synthesizing the two aspects of the research (AR and competence), we can now formulate the following research question: Which competencies are key for implementing a specific augmented reality environment from an industrial engineer's perspective?

2. Materials and Methods

As the research question implies, the main objective is to explore the readiness of industrial engineers to exploit the possibilities of user-generated customized metadata visualization in AR environments. Current industrial engineers are, and must be (as already indicated), educated in multidisciplinary environments [57]. Working with information technology, application development, and programming, in general, is just one aspect of being an industrial engineer. Graduates in this field will have typically completed the following computer science courses: basic programming, basic data processing and evaluation, possibly simulation, and other advanced database courses [58].

The basic motivation for conducting this research is to identify the key competencies needed to create an augmented reality environment so that the findings can be reflected later in the educational process. The assumption is that the most important competencies will be identified based on the senior students' views, which can then be worked with in the follow-up research. Within the study described below, we identify not only the most important competencies, but also list those that are not known to the participating students at all.

As already indicated, we will present here two new methods for creating new digital content for AR by expert users—industrial engineers.

- Option A—Help Lightning Fieldbit (FB)—the FB option uses Help Lightning, Fieldbit's COTS (commercial off-the-shelf) product, and user connection to the IoT infrastructure.
- Option B—Unity3D and Vuforia (UV)—the UV option is definitely more challenging to implement. However, it offers fundamentally more extensive possibilities in terms of development and overall output. Although it is possible to work in a "non-programmer" way, this option offers extended options for associated functionality.

We will describe further both FB and UV options, then we will present the methodology for validating both options. Methodologically, quantitative analysis methods are followed in a similar way as in [59]. We will apply the selected scientific methods in accordance with [60]. The key comparative papers are [50,56,61]. These papers investigate the general relationship of programmer competencies; the key limiting factor of our paper is the focus on industrial engineers. In addition to this limiting factor, other limiting factors in relation to the tested group are the following:

- Products were tested within the Czech Republic's education system;
- Students from the Faculty of Engineering were selected;
- Testing was carried out on final-year Industrial Engineering students; and
- The students were introduced to the issues in the form of multimedia frontal teaching (it was not a hands-on experience).

We visualized the algorithmic workflow of these options (FB and UV) in Figure 1. First, we describe in more detail the algorithm of working in both options for developing a user solution for displaying metadata in an enterprise using augmented reality. Then, we describe how the issue will be presented to industrial engineers, what attributes will be tracked, and how they will be evaluated.

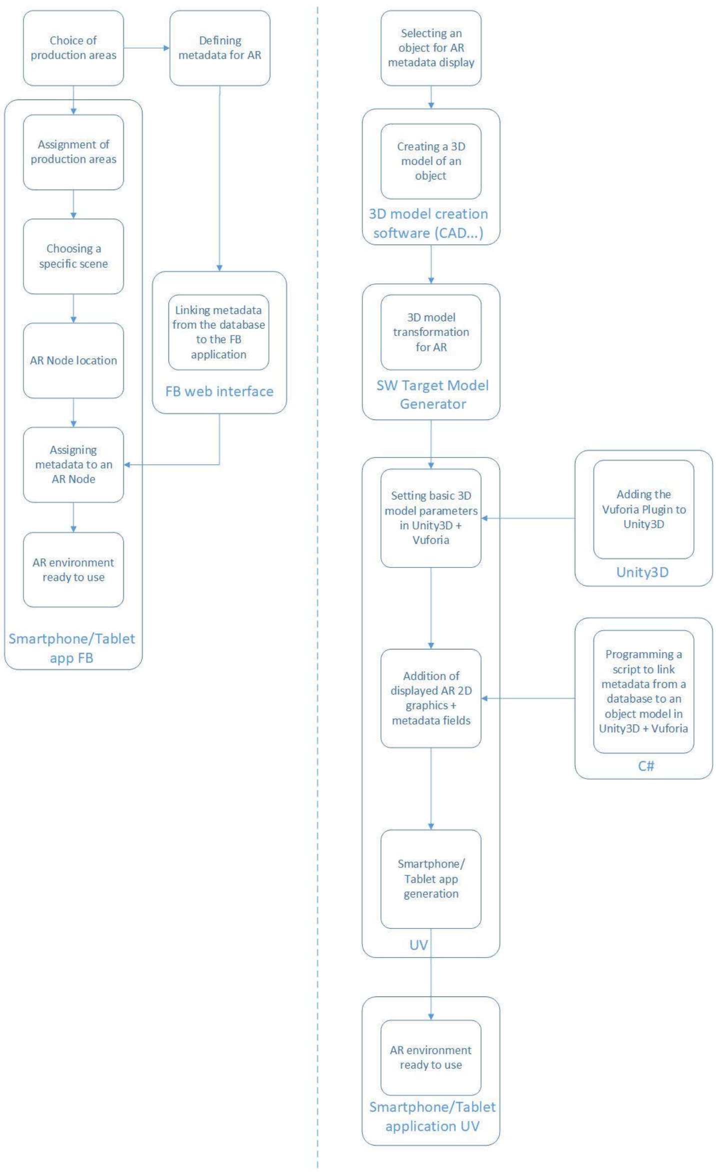

Figure 1. Help Lightning Fieldbit (**left** side), Unity3D, and Vuforia (**right** side) with SW applications applied.

2.1. Description of the Work for Each Option

Both approaches (FB and UV) focus on creating augmented reality environments with varying degrees of complexity and user requirements. We chose them so that each represents a different approach from the perspective of the worker who will be using the software tools and preparing and setting up the content for the end user. The specialization of this development worker as mentioned above is that of an industrial engineer. The end user can be from a variety of professions for which augmented reality information needs to be displayed, e.g., service operator, supervisor, machine operator, etc.

The sub-procedures are based on specific software tools that are the basis for each method and the procedures are named after them. The procedures/tools used were Help Lightning Fieldbit (FB) and Unity with the Vuforia extension (UV). In general, they can be distinguished in that Help Lightning Fieldbit is a ready-made solution with limited possibilities for adjusting the individual data displayed in augmented reality, and Unity with the Vuforia extension is a development environment where most of the details can be set up, but at the cost of requiring more knowledge, experience, and time to create the final application.

It is of course possible to make a generalization of these methods based on the similarity of other tools to one of the mentioned tools. We currently do not have information about a similar industrial AR solution to FB; therefore, we took it as the main reference tool. There are mostly industrial ready-made AR solutions linked to remote assistance, but not for similar purposes of industrial display of metadata. Regarding an alternative to the UV tool, it can be stated that working in the Unreal Engine in combination with the Vuforia plugin can provide similar results. We chose the UV tool both due to the easier creation of an AR application and due to one university course that the probands of this study survey are attending; it is, therefore, easier to explain them.

2.1.1. Help Lightning Fieldbit (FB)

The FB method is based on Help Lightning Fieldbit. This augmented reality application provides the required functionality—displaying online data associated with a specific machine/device in augmented reality. It is a ready-to-use application based on scanning a selected area and selecting a location to place a specific AR NOD to display the required data. An example of the resulting display of real-time power consumption data, which is created using the procedure with Help Lightning Fieldbit, is shown in Figure 2.

The application also provides other functionalities, such as navigation and connecting the augmented reality to knowledge items (for example, video, pdf files, etc.). The principle of the knowledge items functionality is that you can see not only online data linked to a specific machine/equipment, but you also have easy access to its manual, etc. The principle of navigation functionality is that once you are in a scene you can search for a specific instrument or sensor (previously linked to AR NODE). The application guides the user to the device [62].

The software uses a 3D markerless tracking approach, which means that additional virtual artifacts are placed in the scene based on scanning and analysis of real objects.

The workflow with this tool is as follows (see Figure 3). A specific area within the production area is selected where the augmented reality functionality is required. The aim is to display certain data, either in the form of real-time data or by adding additional information (manual, technical drawings, etc.), or simply by marking a specific object. The selected area is then scanned using Help Lightning's smartphone/tablet app, Fieldbit. If an object is spotted in the application which has associated AR information, a touch of the smartphone/tablet screen at the object location is sufficient. This results in a so-called AR node, which is then always displayed in the app when it is passed by. It is, therefore, tied to the place where it was created.

Figure 2. AR node—user view.

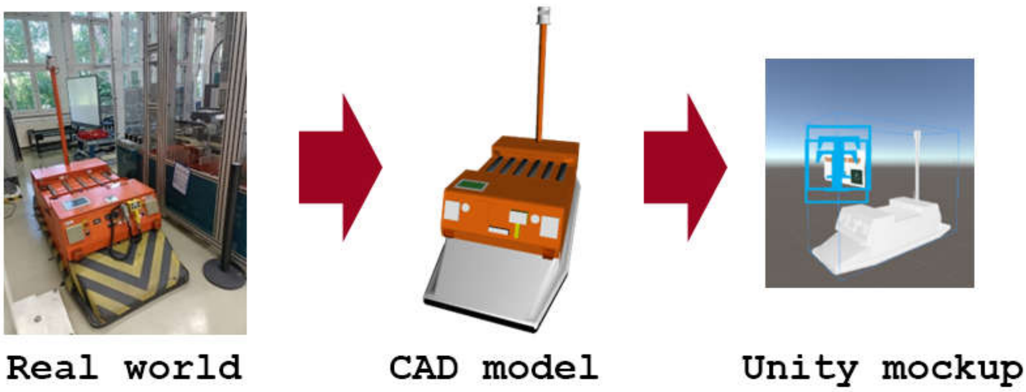

Figure 3. Object processing workflow for the UV option.

Using a web app (different from a smartphone app), you need to set up a connection to a server with user data (e.g., power consumption data). Direct access to the database or API access is supported. Here, the individual parameters related to the server and data transfer via the MQTT protocol are defined. As a result, individual data streams are prepared for specific devices. It is then possible to assign the prepared specific data streams to individual AR nodes (again via the smartphone/tablet app) and display the resulting data streams.

The advantage of the solution is that it is easy and fast to use as a predefined solution, the disadvantage is that it is less configurable and the tool focuses on static (non-moving) objects.

2.1.2. Unity with the Vuforia Expansion (UV)

The procedure for working with this tool is as follows (see Figure 1). First, a suitable area is again selected (typically in the production area of the company) where AR will be deployed. Within the proposed procedure, 3D markerless tracking will also be used. Let us demonstrate a simplified workflow on the example of an AGV. For this object, it is necessary to create a 3D model using a 3D tool so that it can be importable in Unity and Vuforia. Most CAD applications can be used as a 3D tool. Here, the blender tool was used, which supports the import formats of the Unity3D product. In the Vuforia model target generator tool, this 3D model is made available to work in AR. There is a step-by-step selection of the essential parameters important for its final display in AR.

The Unity environment is then used, supplemented by the Vuforia extension, to create a scene into which the model is imported. Next, it is necessary to create the graphics (usually 2D) that are intended to be displayed in the AR.

The entire workflow of processing a single sub-object is visible in Figure 3, including the final preview of the 3D model of the selected AGV in the Unity environment with the Vuforia extension supplemented by the 2D graphics.

The Unity scene is then added to a script created in the C# programming language which Unity works with. The goal of this script is to link data (e.g., power consumption) located on the remote server with the model. The MQTT protocol is used here again. Knowledge of the JSON file format and working with SQL databases is essential.

The final step is to generate a smartphone/tablet app, which the Unity environment allows. However, knowledge of creating these apps is required to properly set up the generation of this app.

This option is, therefore, based on the development and detailed creation of the overall solution (the resulting application). The advantage is the focus on both static and dynamic objects and the possibility of extending additional information with any type of information (video, audio, document, or even any interactive element; for example, a complete 3D model of the assembly supplemented with data from multiple sensors).

2.2. Testing Methodology

The development of a given AR application is very demanding. Within the FB variant, development can take an experienced worker 8–12 h; in the case of the UV variant, it is more likely to result in 60–100 h (depending on the complexity). In the case of a student, it can be up to double the time. In addition, the industrial infrastructure needs to be physically available. We performed all testing and development according to the FB and UV methodologies at a site in Germany. Then we carried out the actual study in the Czech Republic. One of the objectives of the study is also to determine whether the probands will be able to identify the sub-competencies (whether or not they have encountered them). Therefore, no previous experience is appropriate for the purpose of evaluating this aspect. Consequently, for the reasons mentioned above, this study will not use practical AR application development, but it will transfer information from the researcher to the student in the form of interpretation.

A total of 60 min is allocated for presentation and testing. The probands (students) first listen to a presentation and then complete a questionnaire to determine how the competency requirements are perceived in relation to each sub-option (method). Students are in a standard classroom at standard temperature conditions during the presentation and testing.

We selected a total number of 15 students in the last (fifth) year of studies at the Faculty of Mechanical Engineering with a specialization in Industrial Engineering. We conducted this study on the number of industrial engineers available to us, i.e., all students in the last year of study of the specialization. In general, when focusing on industrial engineers, this is a specific and relatively narrow group. These students had not only learned about the theory of industrial engineering but, during their studies, each of them had already solved a specific problem in the field of industrial engineering in practice. In terms of computer science, all of these students have completed the basics of programming (C# or Pascal). They have all completed and implemented a simulation project where they worked with an object-oriented approach. Then, we chose for the actual presentation the class of the database systems in a CIM course.

We created a multimedia presentation that introduces both of the above methods and presents not only the user interface for AR projects, but also presents the background layer. We demonstrated in the form of pictures and videos the process of creating the environment and we discussed in the presentation the technologies that support and enable the implementation according to the given method. To maximize the level of understanding of the presentation, we actively used two projectors, one for the presentation itself and the other for the videos. The presentation alternates between two speakers: one describing the user environment and the other (lecturer of the database systems in the CIM course) and another describing the software architecture of the solution. This presentation is scheduled to last 45 min.

In addition, students fill in two questionnaires; the first one relates to the FB option and the second one to the UV option. The questionnaire is divided into three headings which correspond to the sub-competencies of an industrial engineer, namely soft skills, hard skills, and business skills. The sub-competencies were selected on the basis of a search (see above) and a consultation with a panel of experts. A finer breakdown of the sub-competencies can be seen in the Results section. The range of the Lickert scale for data collection used in the questionnaires was five, i.e., a range from 1 (absolutely necessary knowledge) to 5 (no knowledge needed) with a sixth option, "Not able to assess", added. The basic five-level range was chosen in the context of the Czech education system, which normally grades using levels 1–5 and is, therefore, familiar within the Czech population. Czechs are used to a five-point scale, e.g., from evaluating applications or customer service, etc.

The last slide of the presentation is a summary comparison of the two methods, represented mainly in pictures, so that it is always visible to the students while filling in the questionnaire. The questionnaire itself is then scheduled to take 15 min. Students compare the two options and can preferably use the two-screen stations available to them. The assumption is that students will complete both questionnaires at the same time.

Students will not be limited in time while completing the questionnaire. In fact, beyond the 15 min of completion, a break of an additional 15 min will be announced.

3. Results

We conducted the testing during October 2022 using the introductory part of the database systems in a CIM course. During the testing, two speakers, who are also two of the authors of this paper, were added as planned. We completed the presentations within the allotted time limit of 45 min, and the reaction of the student respondents as to whether the two AR methods in the paper were adequately explained was positive. After the presentation, we gave the students two electronic questionnaires, each relating to one of the methods. During the allotted time for completing the responses, a summary comparison of the two methods was projected as planned. This was positively evaluated by the respondents. The scheduled allotted time for answering was not exceeded and, in fact, some students submitted their answers before the end of the time limit.

The resulting Table 1 shows the competencies which respondents commented on. For the selection of the individual competencies, the method of the expert group (consisting of academic staff in the Department of Industrial Engineering and Management at the Faculty of Mechanical Engineering of the University of West Bohemia) was used, where inspiration was found in the sources mentioned in the introduction, in particular [49,51,52,54–56]. This panel of experts tasked with jointly selecting the appropriate competencies for the survey consisted of experts in business, programming, virtual and augmented reality, and the practical use of computing. Then, we divided the competencies into thematic groups based on [56] into soft skills, hard skills, and business skills. This division was made because of its higher comprehensibility for the target group of respondents and the possibility of unambiguous assignment of the selected competencies to these groups. This basic breakdown will both make the questionnaire easier to navigate for respondents and assessors, and allow for the summarization of values for these groups in the evaluation, which may also provide interesting output information.

Table 1. The results.

Group of Skills	Competence	Help Lightning Fieldbit			Unity3D Plus Vuforia		
-	-	Mean Value	Standard Deviation	Not Able to Rank [%]	Mean Value	Standard Deviation	Not Able to Rank [%]
Soft skills	Ability to analyze problems	2.615	0.961	0.000%	1.385	0.650	0.000%
Soft skills	Ability to analyze risks	2.615	0.961	0.000%	2.077	0.760	0.000%
Soft skills	Ability to solve technical problems	2.846	1.345	0.000%	2.000	1.472	0.000%
Soft skills	Ability to reuse existing solutions	1.769	0.725	0.000%	1.692	1.182	0.000%
Soft skills	Ability to understand other people's code	3.154	1.463	0.000%	2.154	1.345	0.000%
Soft skills	Ability to filter information	2.077	0.760	0.000%	1.692	0.630	0.000%
Soft skills	Ability to search for information	1.769	0.832	0.000%	1.538	0.660	0.000%
Soft skills	Ability to prioritize information	1.923	0.641	0.000%	1.615	0.650	0.000%
Soft skills	Ability to collaborate as a team	2.769	1.092	0.000%	2.077	0.954	0.000%
Soft skills	Ability to analyze data	1.769	0.725	0.000%	1.385	0.506	0.000%
Soft skills	Ability to test the result	1.769	0.832	0.000%	1.538	0.776	0.000%
Soft skills	Ability to work under pressure	2.769	0.927	0.000%	2.500	1.000	7.692%
Soft skills	Ability to think creatively	2.692	1.032	0.000%	1.538	1.198	0.000%
Soft skills	Ability to think abstractly	2.000	0.707	0.000%	1.538	0.519	0.000%
Hard skills	Working with 2D graphics (editing and creating images)	2.846	1.345	0.000%	1.615	0.650	0.000%
Hard skills	User-level working with a smartphone	1.154	0.376	0.000%	1.231	0.439	0.000%
Hard skills	Set up and run a development environment	3.077	1.382	0.000%	1.385	0.870	0.000%
Hard skills	Basic understanding of designing graphics for smartphone applications	2.923	1.256	0.000%	1.462	0.776	0.000%
Hard skills	Ability to compile an app for a mobile operating system	3.167	1.337	7.692%	2.083	0.900	7.692%
Hard skills	Knowledge of XML	3.875	0.835	38.462%	2.000	0.577	46.154%
Hard skills	Knowledge of JSON	3.857	1.464	46.154%	1.667	0.816	53.846%
Hard skills	Knowledge of C#	3.556	1.667	30.769%	1.500	0.707	23.077%
Hard skills	Knowledge of Unity	3.900	1.595	23.077%	1.300	0.675	23.077%
Hard skills	Knowledge of Vuforia	4.400	0.966	23.077%	1.200	0.422	23.077%
Hard skills	Knowledge of SQL	2.909	1.300	15.385%	1.909	0.831	15.385%
Hard skills	Knowledge of 3D tools (Blender, Inventor, Catia, and NX)	3.833	1.030	7.692%	1.667	0.651	7.692%
Hard skills	Basic knowledge of networks (network theory and IP address)	2.333	0.888	7.692%	1.750	0.866	7.692%
Hard skills	Ability to connect to data	1.462	0.776	0.000%	1.231	0.439	0.000%
Hard skills	Knowledge of API/MQTT	2.000	1.118	30.769%	1.444	0.882	30.769%
Hard skills	Basics of database systems	1.917	0.900	7.692%	1.667	0.888	7.692%
Hard skills	Ability to understand data architecture	2.154	0.899	0.000%	1.846	0.899	0.000%
Hard skills	Knowledge of object-oriented design principles	2.769	1.166	0.000%	1.615	0.961	0.000%
Business skills	Ability to understand technical text in English	1.308	0.751	0.000%	1.231	0.439	0.000%
Business skills	Knowledge of project management principles	2.308	1.251	0.000%	1.769	0.725	0.000%
Business skills	Knowledge of agile management principles	2.667	0.985	7.692%	2.364	0.674	15.385%
Business skills	Understand the financial aspects of implementing SW solutions	2.462	1.127	0.000%	1.769	0.725	0.000%

Each competency can be rated with a score based on the Likert scale. The possible scores copy the classification system common in Czech education, so the target group of respondents—students—find it easier to work with the assessment. The values can be chosen from one to five, where one means that the chosen competence is absolutely necessary for an industrial engineer using a particular method. Conversely, a value of five corresponds to the view that competency is not necessary for the particular method for an industrial engineer. Another possible answer, beyond this five-point scale, is "I am unable to rate." This can provide very interesting results for identifying some reserves in the education of industrial engineers with regard to the technologies used.

The total number of respondents was 15 (as already mentioned), which corresponded to the number of completed questionnaires received.

In the resulting Table 1, we detailed the individual competencies with the mean and standard deviation of the scores of the responses. Shown for each competency is the percentage of responses that the respondents were unable to rate. The table shows the results for both Help Lightning Fieldfit (FB) and Unity3D plus Vuforia (UV).

Table 2 is a summary table of the competencies assessed across the competency groups. The columns, i.e., the specific outcome values addressed, correspond to the breakdown of the previous table. The summary is visualized using the graphs in Figures 4 and 5.

Table 2. Rating by skill categories.

Group of Skills	Help Lightning Fieldbit			Unity3D Plus Vuforia		
-	Mean Value	Standard Deviation	Not Able to Rank [%]	Mean Value	Standard Deviation	Not Able to Rank [%]
Soft skills	2.324	1.040	0.000%	1.762	0.951	0.549%
Hard skills	2.813	1.412	13.248%	1.579	0.770	13.675%
Business skills	2.176	1.144	1.923%	1.760	0.744	3.846%

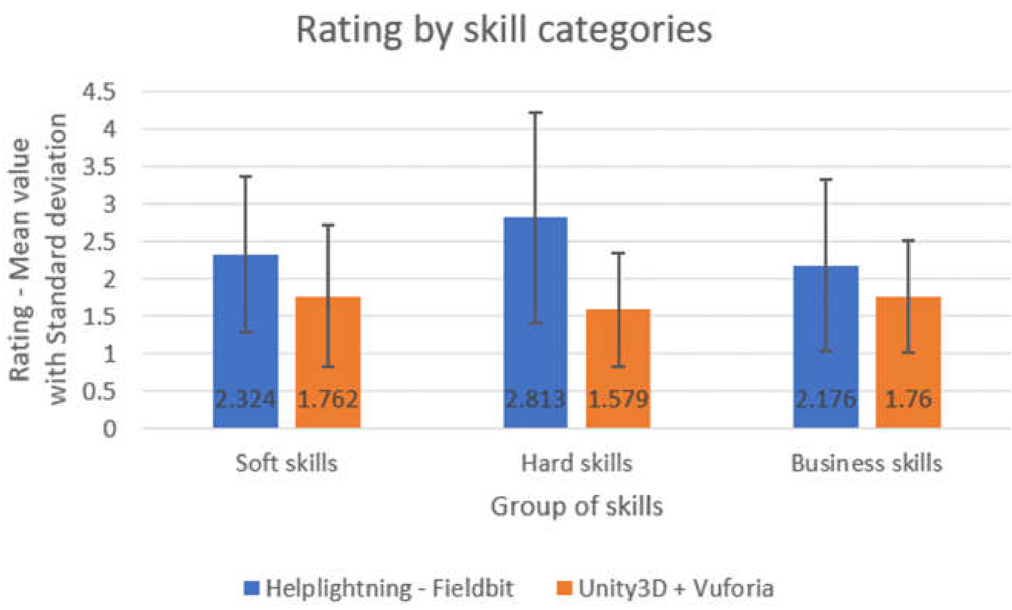

Figure 4. Rating by skill categories—visualization of results.

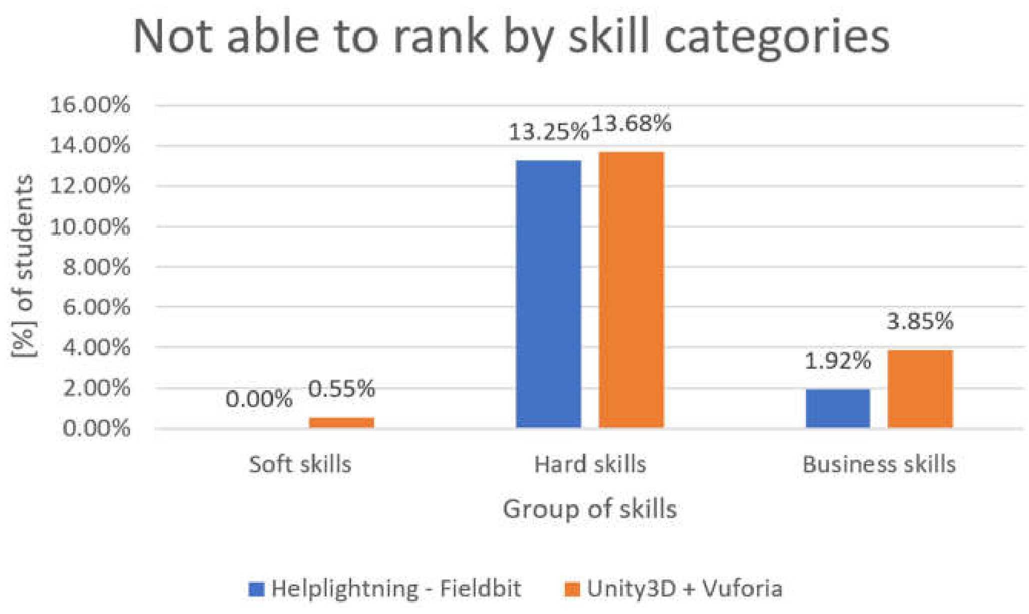

Figure 5. Visualization of probands not able to rank by skill categories.

4. Discussion

If we now focus on the results, we can conclude that, in general, the UV method has a higher need for competencies in all three groups of competencies than the FB method. This fact can be observed by comparing the mean values of the individual competence groups in the summary table. If we look at the standard deviations in the summary table, then the smaller values for the UV method compared to the FB method indicate a higher concentration of respondents' beliefs about a higher need for competencies for the UV method, so there is a more uniform opinion.

When examining the mean values of the individual sub-competencies and comparing them between the UV and FB methods, we can observe that for all but one of the competencies, it can be confirmed that there is an assumption of a need for a higher group of competencies for the UV method. This exception is the competency user level of working with a smartphone. Here, everything points to the correct assumption that in the FB method, the resulting smartphone/tablet application is more versatile, and more operations (AR node placement, etc.,) need to be performed in it. This FB app is already pre-made by the manufacturer, but the environment, object, and metadata assignment is performed in the app. In the UV method, everything needs to be pre-made in Unity3D itself with Vuforia, where most of the settings are already pre-made in the resulting app and usually only launching the app, and pointing the smartphone/tablet camera at the desired object will trigger the desired response. Observing the standard deviations for each sub-competency, the majority opinion is unanimous for the UV method, but there are now six exceptions to this majority, and these are for the following competencies: the ability to solve technical problems, the ability to reuse existing solutions, the ability to prioritize information, the ability to work under pressure, the ability to think creatively, and the previously mentioned user level of working with a smartphone.

The results further show the answers: Not able to rank—that for the group of soft skill competencies, respondents are able to rank almost everything and to comment on almost everything (with one exception—the answers for the UV method and competence: the ability to work under pressure). Consequently, a study and an overview of this field will at least prepare respondents to be able to make more informed decisions about the soft skills needed, as they are more or less familiar with the field.

However, the situation is significantly different for hard skills, with approximately 13% of respondents answering for a specific competency for both methods, such as "Not able to rank". Looking at specific competencies, the most critical are JSON knowledge, XML knowledge, API/MQTT knowledge, C# knowledge, Unity knowledge, and Vuforia knowledge. This may be due to the structure of the respondents' coursework, where the relevant knowledge may have been encountered particularly by those respondents who took relevant elective courses dealing with these areas as part of their studies in industrial engineering. Consequently, a certain lack of education in these areas among the group of respondents is assumed.

In the area of business skills, they are again able to assess and answer almost everything. The number of responses we are unable to rate is, therefore, minimal in this group.

We can now compare the results with those of other authors. In [56], the authors determine the competencies of programmers with respect to industry and educational institutions. In their paper, they also indicate the degree of expected importance of the respective competency for industry and education respondents. This paper served as one of the inspirations for the development of the competencies in the present paper and has the advantage of a very similar direction, where our present paper does not focus directly on programmers, but on industrial engineers, which is a multidisciplinary specialization including IT knowledge. Additionally, the area of focus is industry, which is extended to include IT superstructure, namely AR.

When comparing the specific result values of the paper and those presented by us, the five most important competencies according to the authors are [56] the use of data structures, the use of existing algorithms and code to solve similar problems (reuse), handle errors (error handling), working with others (teamwork), and debugging programs quickly and efficiently. Based on the mean value, our most needed competencies for the FB method are smartphone user level, the ability to understand technical text in English, the ability to connect to data, the ability to use existing solutions (reuse), and the ability to search for information. For the UV method, the most needed competencies are knowledge of Vuforia, user level of working with a smartphone, the ability to connect to data, the ability to understand technical text in English, and knowledge of Unity. It can be seen that, except for the competency use of existing algorithms and code to solve similar problems (reuse), which is mentioned in the most needed, both in the paper [38] and in the presented FB method, the remaining competencies are different. Based on this, it can be stated that the need for competencies is highly dependent on the resulting solution domain. Although both papers include both industry and IT, the specification of the methods in our paper, specifically for AR, will greatly affect the degree of need for specific competencies. This is also evident when compared to the paper "Competency Framework for Software Engineers" [52], which focuses on ten professions within the software engineering industry. This wide range of professions also led the authors to a significantly higher level of generality in the definition of the individual competencies addressed. Consequently, our published paper—following the paper by the authors of [52]—allows its scope to be broadened and more detailed. Namely, the competencies compiled by us can be conducted based on a questionnaire survey on a selected group of software engineers. The result will then allow us to complement and extend the original paper [52].

5. Conclusions

We proposed two methods/approaches for creating AR content in the form of metadata for sub-objects. This metadata is tied to "live" enterprise data and, at the same time, is ready for visualization using AR. In our case, AR is tested in display mode on a smart device using a screen. Displaying using see-through displays should not be a problem, but this method was not tested in the experiments. In the study of the proposed procedures, the sub-competencies of the end-users, i.e., competent industrial engineers, were tested.

At this point, it is, therefore, possible to return to the research question: Which competencies are key to the implementation of a specific augmented reality environment from the perspective of an industrial engineer?

Based on the survey conducted in the paper, respondents from the industrial engineering field, within two defined methods focused on augmented reality, evaluated the necessary competencies as follows, ranked from most needed to least needed (according to the mean value). First, Table 3 regarding the FB method is presented.

Table 3. Sorted competencies for the FB option.

Help Lightning Fieldbit		
Group of Skills	**Competence**	**Mean Value**
Soft skills	Ability to reuse existing solutions	1.769
Soft skills	Ability to search for information	1.769
Soft skills	Ability to analyze data	1.769
Soft skills	Ability to test the result	1.769
Soft skills	Ability to prioritize information	1.923
Soft skills	Ability to think abstractly	2.000
Soft skills	Ability to filter information	2.077
Soft skills	Ability to analyze problems	2.615
Soft skills	Ability to analyze risks	2.615
Soft skills	Ability to think creatively	2.692
Soft skills	Ability to work as part of a team	2.769
Soft skills	Ability to work under pressure	2.769
Soft skills	Ability to solve technical problems	2.846
Soft skills	Ability to understand foreign code	3.154
Hard skills	User-level working with a smartphone	1.154
Hard skills	Ability to connect to data	1.462
Hard skills	Fundamentals of database systems	1.917
Hard skills	Knowledge of API/MQTT	2.000
Hard skills	Ability to understand data architecture	2.154
Hard skills	Basic knowledge of networking (network theory and IP address)	2.333
Hard skills	Knowledge of object-oriented design principles	2.769
Hard skills	Working with 2D graphics (editing and creating images)	2.846
Hard skills	Knowledge of SQL	2.909
Hard skills	Basic understanding of designing graphics for smartphone applications	2.923
Hard skills	Set up and run a development environment	3.077
Hard skills	Ability to compile an application for a mobile operating system	3.167
Hard skills	Knowledge of C#	3.556
Hard skills	Knowledge of 3D tools (Blender, Inventor, Catia, and NX)	3.833
Hard skills	Knowledge of JSON	3.857
Hard skills	Knowledge of XML	3.875
Hard skills	Knowledge of Unity	3.900
Hard skills	Knowledge of Vuforia	4.400
Business skills	Ability to understand technical text in English	1.308
Business skills	Knowledge of project management principles	2.308
Business skills	Understand the financial aspects of implementing a software solution	2.462
Business skills	Knowledge of agile management principles	2.667

From this table, it is clear that for the FB method it is possible to define (within the constraints mentioned in the paper) the most needed competencies for each group of competencies. Approximately the first quartile of the total number of competencies in each group was always selected. Within the soft skills competency group, we identified the four most needed competencies—corresponding to 28% of the total number of competencies for this group. Specifically, these are the ability to reuse existing solutions, the ability to search for information, the ability to analyze data, and the ability to test the result. As we can see, the first most-needed competence ability to reuse existing solutions is definitely linked to the COTS approach of the FB method, in that the development is limited to the creation in the prepared environment of the FB method. The competence ability to search for information has an interesting position in the most needed competencies of the soft skills group, because most of the information relating to the FB method is already solved based on the COTS approach. It leads to the point that most of the probands are not well-equipped with all of the competencies presented (e.g., competence and knowledge of API/MQTT is not part of the standard courses that probands are attending at the university). The competence ability to analyze data accents the importance of the correct data to be linked with the FB method. The high rank of the competence ability to test the result proves the importance of verification of the implementation of the FB method in a particular environment together with correct data functionality.

For the hard skills competency group, we can identify another 28% or so of the most needed competencies, such as user level working with a smartphone, the ability to connect to data, the fundamentals of database systems, API/MQTT knowledge, and the ability to understand data architecture. The most needed competence of the hard skills is user level working with a smartphone, which is related to the essential role of displaying the

AR data. The rest of the most needed competencies are the ability to connect to data, the fundamentals of database systems, knowledge of API/MQTT, and the ability to understand data architecture that is directly linked to the necessary settings of the FB method.

The ability to understand technical text in English is the most needed competence for the business skills group. This is directly linked to the FB method environment and availability of the latest necessary information mostly only in the English language. Table 4 lists similarly ranked competencies, but now for the UV method.

Table 4. Sorted competencies for the UV option.

Unity3D Plus Vuforia		
Group of Skills	**Competence**	**Mean Value**
Soft skills	Ability to analyze problems	1.385
Soft skills	Ability to analyze data	1.385
Soft skills	Ability to search for information	1.538
Soft skills	Ability to test the result	1.538
Soft skills	Ability to think creatively	1.538
Soft skills	Ability to think abstractly	1.538
Soft skills	Ability to prioritize information	1.615
Soft skills	Ability to reuse existing solutions	1.692
Soft skills	Ability to filter information	1.692
Soft skills	Ability to solve technical problems	2.000
Soft skills	Ability to analyze risks	2.077
Soft skills	Ability to work as part of a team	2.077
Soft skills	Ability to understand other people's code	2.154
Soft skills	Ability to work under pressure	2.500
Hard skills	Knowledge of Vuforia	1.200
Hard skills	User-level working with a smartphone	1.231
Hard skills	Ability to connect to data	1.231
Hard skills	Knowledge of Unity	1.300
Hard skills	Set up and run a development environment	1.385
Hard skills	Knowledge of API/MQTT	1.444
Hard skills	Basic understanding of designing graphics for smartphone apps	1.462
Hard skills	Knowledge of C#	1.500
Hard skills	Working with 2D graphics (editing and creating images)	1.615
Hard skills	Knowledge of object-oriented design principles	1.615
Hard skills	Knowledge of JSON	1.667
Hard skills	Knowledge of 3D tools (Blender, Inventor, Catia, and NX)	1.667
Hard skills	Basics of database systems	1.667
Hard skills	Basic knowledge of networks (network theory and IP address)	1.750
Hard skills	Ability to understand data architecture	1.846
Hard skills	Knowledge of SQL	1.909
Hard skills	Knowledge of XML	2.000
Hard skills	Ability to compile an application for a mobile operating system	2.083
Business skills	Ability to understand technical text in English	1.231
Business skills	Knowledge of project management principles	1.769
Business skills	Understand the financial aspects of implementing a software solution	1.769
Business skills	Knowledge of agile management principles	2.364

The selection of the most needed competencies for the UV method is again based on the first quartile. For the group of soft skills competencies, these are the ability to analyze problems and the ability to analyze data. The other four criteria reached the same mean value, but the ones where the respondents were most confident in their decision were preferred and, therefore, they are the ones with the lowest standard deviation compared to the ability to think abstractly and the ability to search for information. As we can see, the first most needed competence is considered the ability to analyze problems, which is clearly connected to the more difficult development of the final AR application by UV. The ability to analyze data is accented for the considered importance of the correct data to be linked with the UV method (similarly for the FB method). The more difficult development of the final AR application by UV is also linked to the ability to think abstractly together with the ability to search for information.

For the hard skills group, these are knowledge of Vuforia, user level of working with a smartphone, the ability to connect to data, knowledge of Unity and set up, and running a development environment. The importance of detailed knowledge of specific software according to more difficult development can be clearly seen in the most needed competencies: knowledge of Vuforia, knowledge of Unity and set up, and running a development environment. The second most needed competence is again related to the essential role of displaying the AR data; it is, therefore, the competence user level of working with a smartphone. The ability to connect to data is necessary for the basic functionality of the developed application. Under business skills, the competency is the ability to understand technical text in English. This is directly linked to the more complex environment of the UV method and also the availability of the latest necessary information mostly only in English, similar to the FB method.

If we compare the most needed competencies for both FB and UV, then three of the four most needed competencies for soft skills are represented within both methods (although not always in the same order). They are the ability to analyze data, the ability to search for information, and the ability to test the result. For the hard skills group, there are only two common competencies in the first quartile, these are user level of working with a smartphone and the ability to connect to data. For business skills, it is again the competency ability to understand technical text in English. The highest differentiation of the competencies between the FB and UV methods is in the hard skills. This represents the big difference between the COTS approach linked to the FB method and the more detailed and more challenging development of the UV method.

In addition to the main contribution of this paper resulting from answering the main research question, it is important to mention other relevant contributions. One of these is the discovery of gaps in the education of industrial engineers needed to implement AR applications according to the methods mentioned. Educational institutions intending to implement AR can use these findings to their advantage, by adapting their course content based on a comparison with the existing teaching content. It is important to mention here that the authors are also academics and will, therefore, consider the appropriateness of adapting existing courses or creating a new course at their university. This should be performed in such a way that the necessary competencies mentioned above are more integrated into the teaching of the university curriculum. AR is theoretically and practically taught within the respondents' study programs, but only as an elective course in the final year, which some respondents were studying at the time of the survey.

As an additional contribution, we can mention our own proposed AR methods (options). These can serve as a guide and inspiration for similar implementations and research. We are considering that the mentioned methods can be generalized for the alternative (mentioned in Section 2.1) or similar future tools.

The focus of this paper is on targeting industrial engineers but, of course, this area also applies to software engineers and the field of computer science in general. Furthermore, with respect to the metadata concerning power consumption and with respect to the electrical machines and equipment used as the initial basis for the models of the methods, the field is also open to the electrical engineering disciplines.

We see further research directions based on the results of this paper in several areas. One very interesting area of AR applications in pods is the area of in-house navigation using augmented reality, which includes a number of challenges (this direction with related references is mentioned in the introduction). Another useful application is the display of metadata on machines using augmented reality which can be part of a remote assistance system using AR. In enterprise infrastructure it can then, e.g., be part of a complex predictive maintenance system that uses AR as a human–computer interface.

As already mentioned, in the follow-up research, we will focus on the most important competencies identified (in this study), and we expect to involve a larger sample of probands, namely from the lower grades. Due to our request for a higher number of probands, this is likely to be a longer-term study. By conducting the study in lower grades and choosing a longer-term study, we aim to achieve the largest number of participants. We anticipate that probands should practice parts of creating AR environments, namely in the context of learning how to work with AR with a reflection on the necessary competencies. The output can then be a summary comparison of individual competencies needed across multiple areas with a sufficient degree of generalization.

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