

Implementation of UI Methods and UX in VR in Case of 3D Printer Tutorial

Andrzej PASZKIEWICZ^{a,1}, Mateusz SALACH^a, Maria GANZHA^b, Marcin PAPRZYCKI^b, Marek BOLANOWSKI^a, Grzegorz BUDZIK^a, Hubert WÓJCIK^d, Fotios KONSTANTINIDIS^c, and Carlos E. PALAU^d

^a *Rzeszow University of Technology, Rzeszów, Poland*

^b *Systems Research Institute Polish Academy of Sciences, Warszawa, Poland*

^c *Institute of Communication and Computer Systems, Athens, Greece*

^d *Communications Department, Universitat Politècnica de València, Valencia, Spain*

ORCID ID: Andrzej Paszkiewicz <https://orcid.org/0000-0001-7573-3856>, Mateusz Salach <https://orcid.org/0000-0002-9199-3460>, Maria Ganzha <https://orcid.org/0000-0001-7714-4844>, Marcin Paprzycki <https://orcid.org/0000-0002-8069-2152>, Marek Bolanowski <https://orcid.org/0000-0003-4645-967X>, Grzegorz Budzik <https://orcid.org/0000-0003-3598-2860>, Hubert Wójcik <https://orcid.org/0000-0002-1395-9603>, Fotios Konstantinidis <https://orcid.org/0000-0002-1826-6582>, Carlos E. Palau <https://orcid.org/0000-0002-3795-5404>

Abstract. In this work, the development of virtual reality software for “industrial applications” is considered. It is argued that, in this context, the vast experience from the development of computer games cannot be used directly. Especially, the specific nature of solutions dedicated to industrial applications requires taking into account their specificities, needs, and limitations of VR. This brings about the formulation of a domain-specific approach to creation of VR-related courses for the industry. As an example, the development of course concerning the operation of a professional 3D printer, which is used in industry, as well as in prototyping, is discussed. In particular, it is used to illustrate implementation of UI and UX aspects of the developed VR-environment.

Keywords. Virtual Reality, UI, UX, Industry 4.0, 3D printing, training software

1. Introduction

The ongoing fourth industrial revolution has provided advancements and technologies, transforming the traditional manufacturing ecosystem. One category of “next generation” technologies are Virtual Reality (VR) and Augmented Reality (AR), which should be adopted by businesses, in order to quickly and efficiently train their operators and significantly increase their productivity [1,2]. VR has its own, domain specific, criteria that should be taken into account when designing both the interface and the methodology of movement, or interaction with the virtual environment. This applies to both games and other applications. Analysis shows that not all games, or applications, perform well in

¹ Corresponding Author: Andrzej Paszkiewicz, Department of Complex Systems, Faculty of Electrical and Computer Engineering, Rzeszow University of Technology, al. Powstańców Warszawy 12, 35-959 Rzeszów, Poland; E-mail: andrzejp@prz.edu.pl.

virtual environments, compared to the corresponding solutions designed for PCs (e.g. window applications). Here, analysis for, among others, first-person shooters, can be found in [3]. However, in general, the difference may also be related to the fact that some games that, by default, were designed for the PC, were not correctly adapted to VR. Key aspects, in this context, are appropriate UI (User Interface) and UX (User Experience), which have been adapted to the specifics of virtual environments. It should be noted that, regardless of the model of VR glasses, a poorly implemented UI may prevent a favourable impression of the VR environment. On the other hand, an important factor, in the case of UX in relation to desktop, console and virtual reality games, is the possibility of interaction (e.g., input device). The user can use a standard keyboard, or a gaming pad, while, when using virtual reality, additionally has in her/his disposal dedicated VR controllers. Studies, like the one found in [4], indicate that choosing the right controller significantly affects the user gaming experience. Here, the main criterion is the “naturalness” of using given input device. The more natural the movements, the better the gaming experience. Therefore, UX and UI are the key components of valuable VR software. Moreover, since they affect user perception and feedback, they are essential to the commercial success of VR. Separately, UX in VR is particularly important for solutions dedicated to the industry. A good selection of elements and programming the right interactions with the environment is important in medicine [4,5,6], aerospace, automotive industry [1,8], construction field [9] and factories [10,11]. In such broad applications of VR, emotions also play an important role in the relationship between users and products [12].

At this point, it should be emphasised that VR has tremendous potential to train users (e.g., engineers) in the area of expensive, hard-to-reach, novel technologies and processes [13,14,15]. In this context, one should note that preparation of VR-based tutorials is related to the transfer of the actual product/device/technological line to the virtual reality. As a result of such a process, a digital twin [16] is created, representing not only a physical object, process, system, but also its functionality. Such a digital twin should match the original as closely as possible. At the same time, it must be adapted to work in VR. For the specific implementations, factors that have to be considered are the user interface and the “clickability”. In addition, the virtual elements, which are the focal elements in the course, must be properly scaled, without affecting the reception and the functionality of a given object, e.g., a machine. VR trainings can also be found in the area of railways [17]. In this work, a specific training system has been developed for engineers for maintaining crane movement, in case of railway accidents on railroads. As a matter of fact, the usage of VR in industrial environment necessitates the highest possible level of realism, while ensuring convenience and efficiency of operation. This is in contrast to VR games, where the virtual environment can be completely imaginary, with unrealistic objects, different laws of physics, or an unrealistic scale and interaction. Therefore, majority of previous experience, gained in the development of computer (VR) games is insufficient, as it applies to a completely different operating environment.

In this context, the following contribution presents the results of work on UI and UX aspects of VR, undertaken when creating VR software for training in the use of professional 3D printers. The rapid development of additive technologies and their application in the aviation, consumer, medicine, education, culture and widely understood prototyping industries, requires training large number of users and/or service personnel. Apart from that, the use case of 3D printing is also selected due to the fact that enterprise has not widely used this technology, due to the lack of experienced operators. Hence, it results in the need to develop new and effective training methods

[18]. It should be noted that, in majority of cases, training on actual machines (3D printers) involves, among others, high costs, limited access, numerous losses, and waste of manufacturing materials. This being the case, existence of VR-based training materials enables repetitive activities, unlimited time and access to digital machines, and significant overall cost reduction. Finally, considering the last two years, an important factor is also the limitation of on-site course availability, during COVID-19 pandemics. In such a situation, virtual training can provide continuity to the teaching process.

2. Designing the methodology for VR software development

Through the decade of software evolution, numerous software development methodologies have been proposed [19,20,21,22]. They resulted from many years of experience, but also from the challenges posed by globalization, the development of new technological areas, or customer requirements. However, above all, they have been influenced by the pursuit of maximization of efficiency, i.e., providing key (useful) functionalities in the shortest possible time. The majority of UX/UI-related approaches consist of five stages: *Empathize*, *Define*, *Ideate*, *Prototype* and *Test* [23,24]. Depending on the approach, a different number of feedback loops, between stages, is considered. This approach is generic and applicable in many areas. However, this work focuses on the needs of software development for VR software utilised in industry. Therefore, a six-phase methodology has been proposed for development of VR training materials [25]. These six phases are *concept*, *preparation*, *implementation*, *operational*, *real production* and *evaluation* (see, Fig. 1). Each of these phases is a separate part of the process and none of them can be omitted. The proposed methodology has been initially tested in the development of different VR environments for aerospace, prototyping, manufacturing process control, and network engineering education. Most recently, it has been complemented with UI/UX aspects.

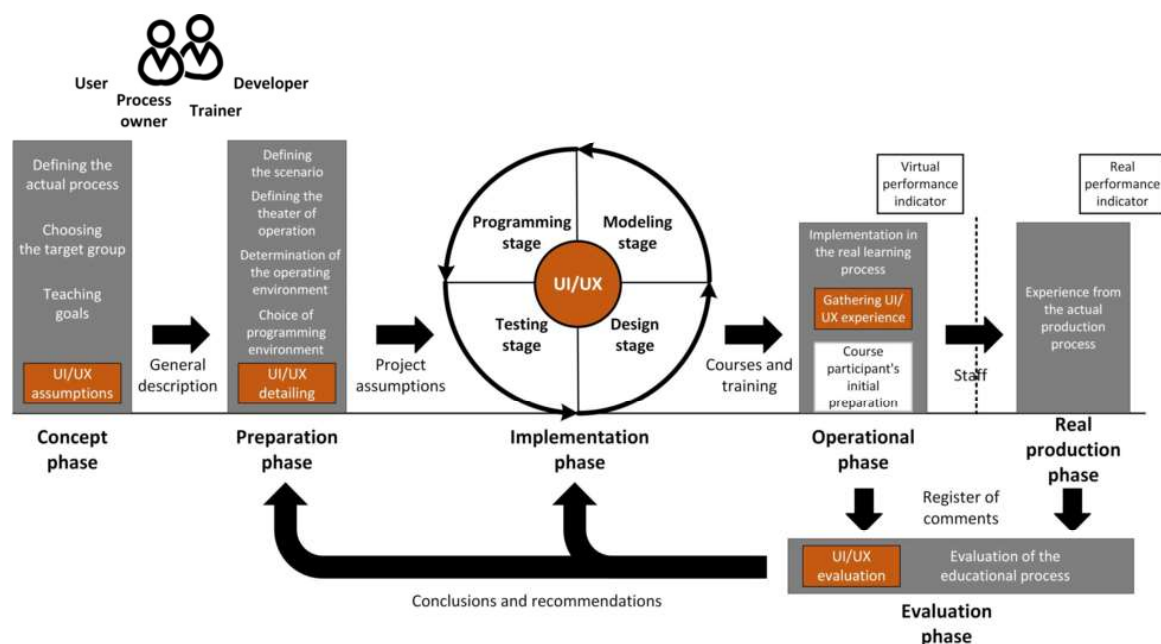


Figure 1. Methodology for developing VR training dedicated to industry needs.

According to the adopted methodology, the actual process is defined in the concept phase. In the case of UI/UX, the initial assumptions, requirements, and expectations from the end-user point of view, should be formulated and included there. From this perspective, the selection of the right target group of users will also help to define the UI/UX assumptions, while the detailed information about UI/UX is gathered throughout the preparation phase. These activities must be related to a detailed description of the training scenario(s), modelled objects and their functionality, as well as the production environment adopted for the actual implementation. The implementation phase consists of four sub-stages. Proper implementation of UI/UX assumptions must relate to all of these four sub-stages as a whole. It is during these stages that the specific interaction mechanisms are implemented, regarding functioning of individual objects (including buttons, levers, control and display panels), as well as user-virtual object interaction(s), or a hint system (existence of which is also very important). In order to achieve the appropriate UI/UX functioning, its development cannot be considered independently at each stage of this phase. Teams involved in individual work must cooperate during system implementation. The use phase concerns the implementation of the training. Both qualified trainers, and representatives of the target user group, have to be directly involved in this phase. At this point, the experiences, the suggestions and the observations of both the users themselves, and those with experience in the field of training using VR technology, are collected. They are also used to evaluate the solution, in terms of UI/UX and its further improvement.

The preparation of the VR environment, the UI/UX elements should be conceptualized including the following aspects (this list is not meant to be exhaustive):

- text readability,
- appropriate refresh rate,
- ergonomics of work,
- avoidance of sudden changes in brightness,
- arrangement of buttons and other controls,
- avoidance of simulator sickness.

However, in the case of VR environments, dedicated to the industrial needs, the following factors must also be taken into account:

- Details – which are important from an operator/engineer/user perspective. In the case of industrial systems, the attractiveness of individual elements is less important, and the availability of specific (necessary in the context of a given machinery) components and functionalities is more important.
- Safety – determination of safe work zones that reflect the production work environment. This aspect is crucial in shaping the proper behaviour of future operators/engineers.
- Hint system – during industrial training, the hint system plays a very important role in advising the user what to do and, possibly, how. Such a system can be placed in the form of a virtual screen at one of the virtual hands of the operator (onboarding helper), in a special information window, etc. It is important that it is easy to read/understand and has the ability to turn the hints on and off.
- User focus – when delivering industry-specific courses, one of the most critical aspects is maintaining user focus. Therefore, the quantity of information they receive from the surrounding VR should be limited to the data that may be actually found in a real environment, and should avoid overly overemphasising features that are irrelevant to the specific training scenario.

- Physical processes and phenomena – when recreating industrial processes, it is important to consider a high level of realism of the created processes and implemented phenomena. However, due to their complexity and, at the same time, lack of user interaction in certain cases, there is a possibility to simplify them, such as the 3D printing procedure, or milling process in the CNC machines. This makes it possible to shorten the duration of lengthy procedures in which the user him/herself is not involved.

The presented methodology, as well as the above UI/UX aspects, were considered when creating the 3D printer training environment.

3. Developing the 3D printing tutorial

The aim of the practical part of the project, in which the proposed approach to VR software development was applied, was to develop a training for users, who have no experience with 3D printing and 3D printer operation. Using the proposed VR software, unexperienced users can learn to operate a 3D printing machine without additional physical training procedures, reducing significantly the faults in the real assets. Despite the fact that the VR-based training software was developed for the specific 3D printer model, namely the Stratasys F170, it can be easily modified and adapted to be used with any 3D printer. The 3D model of the printer was designed in Blender 3D, in accordance with printers' actual dimensions and characteristics, as shown in Fig. 2, while the entire project was made using the Unreal Engine 4 game engine. The 3D design software was used because the graphical representation of the considered 3D printer was not available online. This additional work increased the training software development time.



Figure 2. 3D model of Stratasys F170 3D printer in Unreal Engine 4.

It is widely accepted that the accuracy of components and details increases the reliability of the training procedures, especially for industrial (training/use) applications. However, obviously, even in gaming, observance of details of a given object may play an important role, as it may have positive effect on the user's reactions. However, in the case of industrial VR applications, attention to details increases the level of confidence, as the user are “assured” that she/he is working with a “perfect copy” of a given element. Apart from the visual elements, the training method itself is also important. The users who perform a specific training path, on a virtual machine in a VR environment, should gain the capability to operate the real (physical) device. Finally, creating and visualising

detailed elements may lead users to come back, or take part in the training for the first time. Hence, the graphical aspects of the real-world elements should be taken into account. An example of the training for industry is a specific 3D printer operation scenario, which assumes a sequence of tasks performed by the user in interaction with the device and with elements of the environment. The user path is presented in Fig. 3. In the context of the presented application, the main goal of VR training is to guide the user through the entire process of operating the 3D printer, starting from approaching the machine, and finalising it with removing the finished 3D print. Note that the first stage of the training was focused on the usability of the device itself. Here, 3D design prototyping would require a different training environment. Moving into the virtual world, the user has to enable the 3D printer, by pressing the Power button, which is located next to the 3D printer screen. As noted above, interactive elements, in virtual reality, are developed in a very different way. They must be customizable to be able to be pressed/switched with a VR controller, while still maintaining compatibility with the original element (that is part of the actual device). In the case of the 3D printer, the power button was added in a compatible size with the device, and the collision area with the object 'switch' was slightly enlarged to make it easier to turn the button. The next step is to open the flap and insert the filament. The user has two spools at their disposal, which should be placed in the area intended for the filament. After closing the flap, the user should mount the table on the heating top, for the 3D printing. The next step is to start the 3D printing. In the first stage of training, the user can print only one predefined 3D model. To enhance the user experience, the waiting time to print was significantly reduced, as the training focuses mainly on the operation of the 3D printer, rather than the actual 3D printing. In the second stage of the VR training procedure, modifiers (parameters) of the printout should be set, simulating some of the parameters from the slicer, i.e., a program for converting *stl* files to *gcode*. The user should learn the rules of parameter selection and how changing specific parameters affects the printed object. In the future, new scenarios of printed elements could (and should) be added, e.g. based on different additive methods (print material).

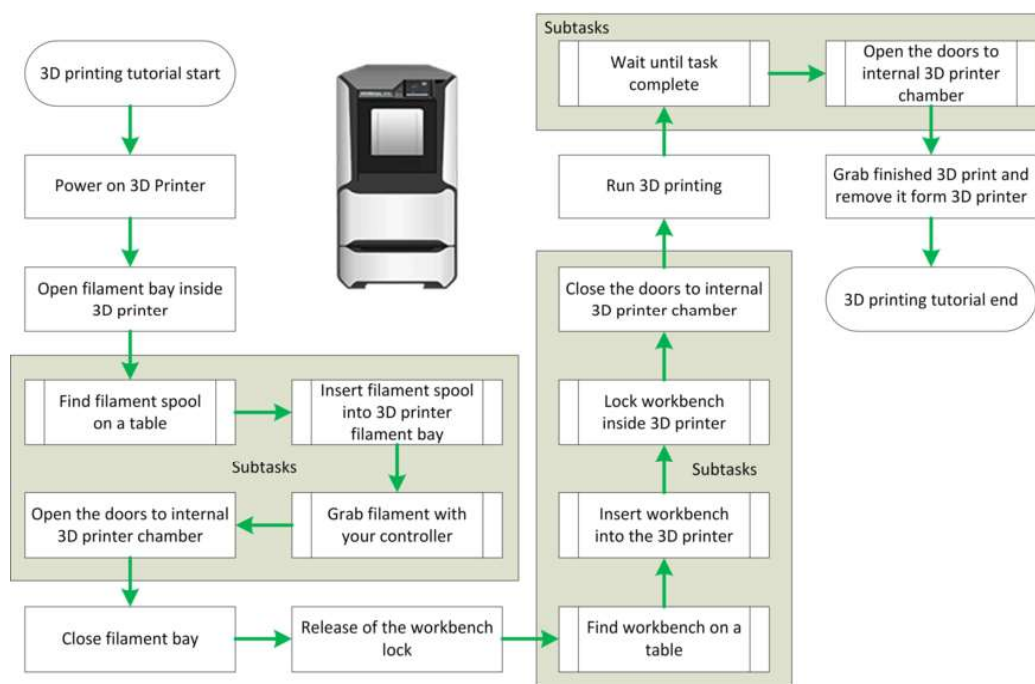


Figure 3. 3D printer tutorial scenario.

4. Designing applications in VR

Designing both applications and games, using a dedicated graphics engine in VR has its own additional guidelines, related to both interface and player/user feel, compared to typical desktop applications and games. However, in the case of VR projects, graphic design is divided into virtual environment and virtual interface. The virtual environment is the scene that surrounds the player. It includes all the elements of the scenery, 3D models, mapping of the surroundings/devices and finishing elements, while the latter one includes the elements that can be interacted with, even if they are solid objects. The emphasis on UI is more significant in VR, compared to the traditional desktop applications/games. In the desktop-based application, improper placement of interface elements (buttons, links, maps, shortcuts), while it has a negative impact on the reception of the product, it is less conspicuous than improper placement of interface elements in VR applications. As what concerns the virtual reality applications, elements that overlap or are small, blurred, etc., may result in an inability to interact with the application or the game. For example, if a player (or a user), cannot complete a task due to overlapping or overwriting colliders, the application or game stops the user at that moment, without the ability to move. Additionally, the choice of the environment, interface, design and its rational implementation, define the structure of the game/application, its playability, and intuitiveness (Fig. 4). Maintaining the balance, and accurate mapping of object structures in industrial applications, plays an even more significant role.

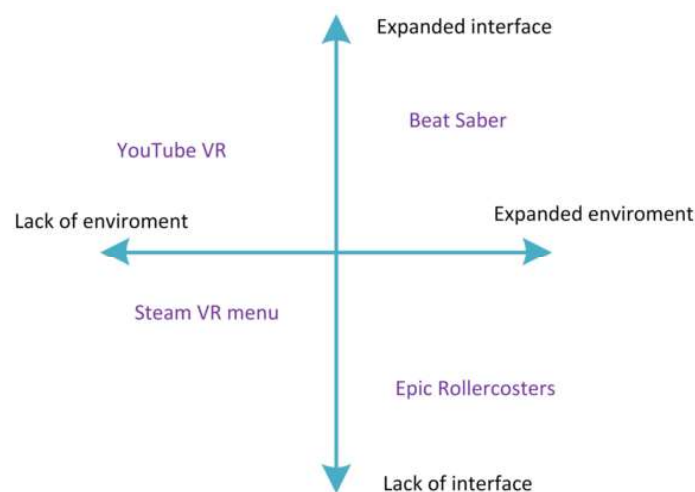


Figure 4. The relationship of the interface and the environment on the example of selected VR programs/games.

An example of applications, with minimized interface, can be found in roller coaster games, where the user has to sit down and enjoy the ride. Scenery moves by itself, so the user does not need to perform any actions related to the control of the “trolley”. An example of a more complex interface, or an increase in the number of clickable elements, is the Steam interface in VR. Applications and games must be designed in such a way that the user, wearing VR glasses, can freely interact with the environment and feel full immersion. Immersion in VR affects not only the quality of the performance and the desire to use the application (again), but also the physical health, so it has to be one of the crucial elements taken into account during the process of designing games/applications in VR. For instance, too low number of frames per second (FPS) may have very negative effect on the body's behaviour. The participant, among other things,

may get nauseous and her/his head may “spin”. Constancy, and higher number of frames per second, significantly affect the reception of applications/games in VR goggles, so the minimum number of FPS in virtual reality is recommended to be 60 frames per second. This is the optimal value at which the human body should behave stably, and which should allow to freely use the VR goggles. Another element that affects the positive feeling of the body is blocking the virtual shift. User looking through virtual goggles, although subconsciously knowing that they are in the goggles, relies on stimuli and senses that can react unfavourably for the user if unusual actions are performed. Here, a typical example is the virtual player displacement, or VR sickness. A popular aspect of many VR goggles is the ability to move around a room after a safe virtual boundary has been set. Even though the user knows that they are enclosed in virtual reality, both the senses and muscles feel what the eyes see. It is then natural to move the body when one needs to move, or “dodge”, in the game. However, it is unnatural to move the player in virtual reality without forcing physical movement. This can cause nausea and significantly reduce the user experience of the game/application. For virtual reality-based solutions, natural methodologies should be used to lie to the human senses. For instance, in the case of virtual distance movement, the teleportation technique is used (Fig. 5) and in the case of characters moving at higher speeds (e.g., running), virtual eye caps are used, to reduce the visual area.

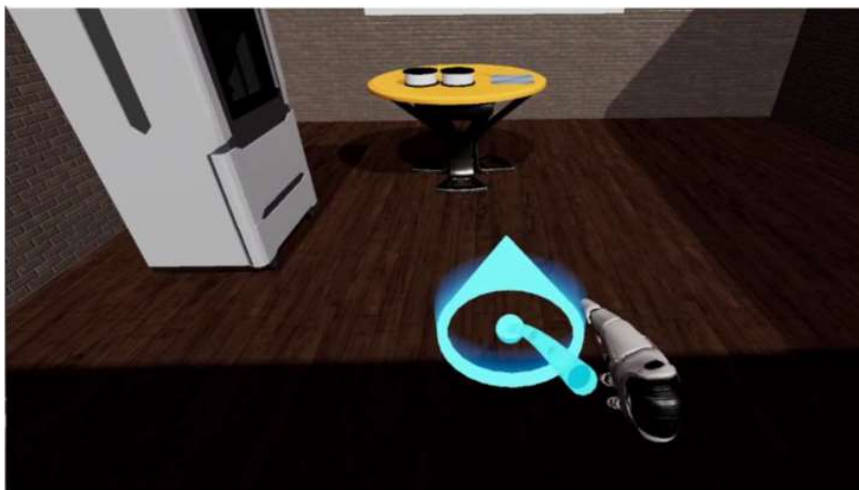


Figure 5. A demonstration of the teleportation technique popular in virtual reality.

This allows the user to focus on a smaller, fixed image, which positively affects the spatial feeling of the user. The above described techniques significantly affect the positive user experience of the application/game, and the overall feeling of virtual reality. These are very important aspect of application/game design. However, to ensure that the user’s VR experience is positive, the interface and environment should be properly designed. For VR, small elements with text should be avoided. Even after approaching the object with a high density of goggle pixels, the text may be too difficult to read. An increased number of pop-up windows can take up a lot of screen space, and each additional element, in the form of a window occupying the displayed environment, negatively affects the experience and the effect of immersion. Overall, the number of windows associated with the display of information and messages should be kept to a minimum. It is widely recommended, in the development of VR applications, to add tutorials for moving around in the virtual world, when starting a game/using an app. An assigned VR-use tutorial allows the user to familiarize with the assigned controllers and

movement options, especially for people who do not have previous experience with VR, or have used other controllers. It is necessary to focus user's attention squarely on the commands, and to minimize distractions at any given time. The industry training tutorial helps new users get started intuitively and hassle-free. Often, people undergoing training on a particular device have no experience with virtual reality, making visualization of motion capabilities in VR an elementary determinant for them to attend a training course.

Focus in VR solutions is most often achieved by directing the user – her/his attention to the appropriate feature, by highlighting elements, which the user should interact with. It can be a button on a printer, or a joystick on VR controller for movement. The user then knows what action is to be performed. During the development of the application, discussed in this contribution, challenges occurred concerning appearance of the 3D printing machine. In the virtual reality application, the view of photos/videos is different, because the images must be properly scaled and must be of high resolution so that the user can read the text contained therein, without any major problems. As an example of the issue that had to be solved, consider the fact that the Stratasys F170 device has a touch screen, on which user sets parameters and starts printing (Fig. 6). The screen used in the actual device is small, which is highly undesirable in virtual reality.



Figure 6. Visualization of the touch panel of a 3D printer in virtual reality.

Therefore, it is necessary to perform mapping, to give the user ability to virtually click on various elements of the touch-screen. To increase the clicking experience of the user, additional methods were followed to overcome the following challenges. First, while the screen is small, its enlargement in VR could significantly affect the reality of the object. The second difficult part was to add the menu view to the VR environment. Due to the lack of available 3D model of the printer and its components, a photo of the screen has been added. Unfortunately, the quality and the reflection of light, negatively affected the visualization of the screen, in the virtual environment (Fig. 7). To maintain high quality and accuracy, a copy of the screen was created, using the Unreal Motion Graphics tool, built into the Unreal Engine 4, and the vector graphics programs. The result is shown in Fig. 8.

While developing the VR tutorial for operating the virtual 3D printer, the display is clickable, such that the user can start the printout step by step, by pressing the appropriate commands on the display. To program such an action, two modifications had to be applied, namely the invisible colliders had to be introduced. The first collider was placed above the screen. In the event of a collision of the virtual hand (controller) with the collider, the hand performed an animation of pointing to a specific element. Only the index finger was extended, while the remaining fingers were “folded into a fist”. The

second collider was placed under the screen, under the button that had to be clicked. When there was a collision with the second collider, it was assumed that the user had pressed the screen. This caused the screen image to change, bringing about the rest of the menu, until the printing process has been started. The view of this function within the VR application is shown in Figure 9.



Figure 7. Screen shot of the real 3D printer model.

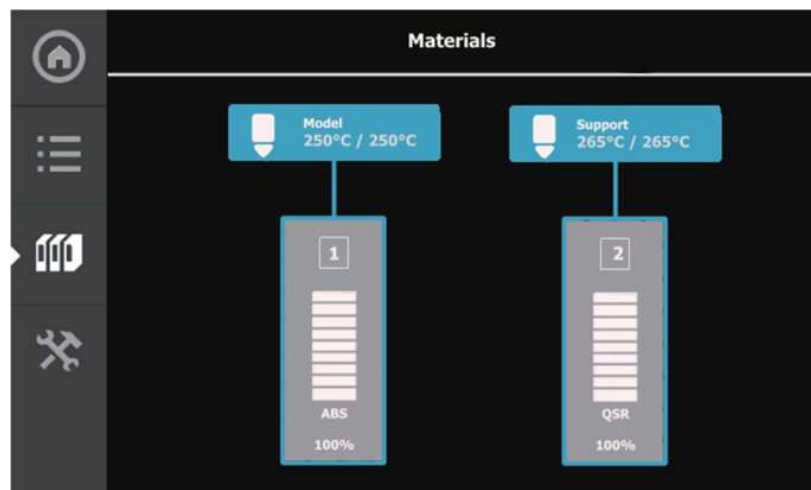


Figure 8. A display made in graphics programs designed for virtual reality.

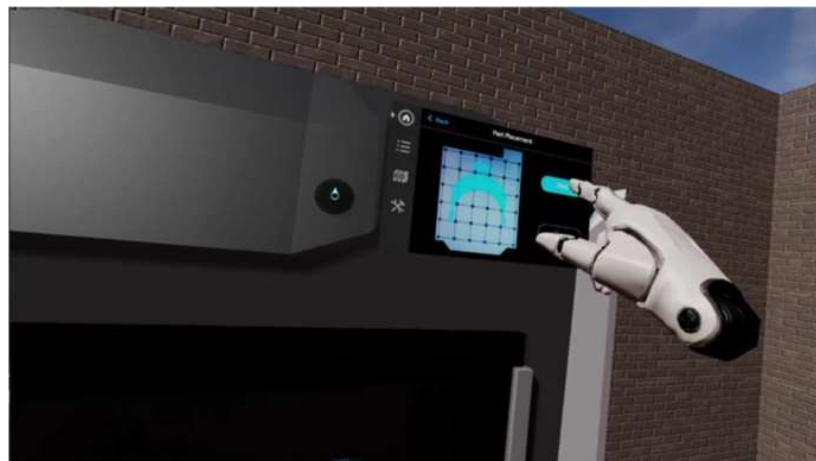


Figure 9. Visualization of object collisions - hand controller and screen leader. The movement of pressing the button is animated

5. Concluding remarks

One of the basics of a well-made, and used by multiple users applications, is a well-made interface, compliant with relevant standards, and a skilfully presented user experience. An interface designed for users interacting with virtual reality-based applications must provide them with the flexibility to navigate and interact with the virtual world. While the amount of work dedicated to the development of VR-based games is large, industrial VR application need a number of additional aspects to be considered. In this context, an approach to the development of VR-based industrial applications, with special attention paid to the UX/UI aspects, is proposed. This approach is an integral part of the methodology developed, specifically, for the development of VR-based training. Until now, there has not been such a comprehensive approach that also takes into account the diverse factors relevant to industry-dedicated solutions. Next, a VR-based training application, intended for future users of an industrial 3D printer, has been discussed to illustrate selected key aspects of the proposed approach “in action”. Among others, user interaction capabilities and matching of the scale of objects to the displayed image were considered. Reported results are anchored in an actual application that has been designed and implemented, and is fully functional. In the near future, as the VR-tutorial will be further developed, one of important directions of work will be directed towards user-focused content customization. We will report it in subsequent publications.

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