IMMERSIVE TECHNOLOGIES THAT AID ADDITIVE MANUFACTURING PROCESSES IN CBRN DEFENCE INDUSTRY

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Abstract: Testing unique devices or their counterparts for CBRN (C-chemical, B-biological, R-radiological, N-nuclear) defense relies on additive manufacturing processes. Immersive technologies aid additive manufacturing. Their use not only helps understand the manufacturing processes, but also improves the design and quality of the products. This article aims to propose an approach to testing CBRN reconnaissance hand-held products developed by additive manufacturing. According to the approach, tactical training with the use of the 3D object or their printed versions can be helpful in military products development by providing data on user experience. Training for testing can enhance their quality regarding intuitiveness and easiness in use. It can be concluded that the fast-evolving technological landscape requires novel approaches in developing and testing military products.

Key words: Immersive technologies, Virtual Reality, Mixed Reality, Augmented Reality, Additive Manufacturing, CBRN reconnaissance devices testing, CBRN defence tactical training.

1. INTRODUCTION

Industry 4.0 is an evolving umbrella concept used interchangeably with “smart manufacturing”, “digital transformation”. It applies to specific changes in a production process which relies on key elements such as big data, smart factories, cyber physical systems, Internet of things. Industry 4.0 promotes the integration of advanced technologies such as additive manufacturing (AM), or 3D printing, which is the application of digital tools in designing, manufacturing, using, and servicing products. AM is used not only by civilian producers, but also in defence industry.

Often, it is connected with the extensive use of Virtual Reality (VR), Augmented Reality (AR), or their connection - Mixed Reality (MR). The above technologies serve as environments or tools which allow for better visualization and explanation of manufacturing processes, or products' specification. VR is "a digital artificial environment that makes the human-senses to perceive something and experience it as real" [1], AR, "integrates digital information in the form of virtual objects (e.g., text, video, 3D model, audio, haptic and so on) with a real environment" [2], and MR combines real world and digital elements [3]. In MR environment, real and computer-generated objects can coexist and interact. The use of VR, AR and MR, so called "immersive technologies" [4] for AM purposes brings promises for the chemical, biological, radiological, and nuclear (CBRN) defence industry, which focuses on technology development. One of the solutions developed in the field of CBRN defence are reconnaissance (recon) tools or equipment. CBRN agents can harm the society through their accidental or deliberate release, dissemination, or impacts. Therefore, novel products are required and also training activities on how to use them are needed. Soldiers have to possess relevant competences on how to apply CBRN reconnaissance (recon) equipment in hazard detection, identification, and monitoring (DIM) or Medical Countermeasures (MEDCM) and Casualty Care [5], which are often related to stressful conditions.

In this article, we analyse the potential of immersive technologies to enhance AM processes in CBRN recon products development. Firstly, we present the landscape of the technological development in additive manufacturing and immersive technologies; regarding immersive technologies, we particularly focus on a versatile infrastructure - CAVE Automatic Virtual Environment. Secondly, we analyse a scenario on a testing CBRN state-of-the-art recon devices through a tactical training. In such a training, users can interact with the objects visualized in a 3D environment and communicate their preferences as well as get familiar with a new equipment. In the Conclusion we indicate the main advantages of the approach: obtaining either the data on errors related to a designing process, or data on user experience. The proposed approach of using tactical training for user experience research fosters innovations and is conducive to civil-military cooperation in developing state-of-the-art solutions. It can be applied in various military areas.

2. THE LANDSCAPE OF TECHNOLOGICAL DEVELOPMENT – ADDITIVE MANUFACTURING AND IMMERSIVE TECHNOLOGIES

2.1. Additive manufacturing

The universal definition of AM is presented in the standardization document "Standard Terminology for Additive Manufacturing-Coordinate Systems and Test Methodologies". The document describes the concept as "those processes that aggregate materials in order to create objects starting from their three-dimensional mathematical models, usually by overlapping layers and proceeding in the opposite way to what happens in subtractive processes (or by chip removal)" [6]. AM originally was introduced at the end of the 1980s as Rapid Prototyping [7]; it is considered as a novel materials processing approach used in order **to** create parts or prototypes layer-by-layer directly from a computer aided design (CAD) file [8]. In this process, the CAD virtual 3D models are translated into physical objects [9]. The process of AM consists of mainly three phases: the design phase, the processing phase, and the testing phase. The detailed steps are illustrated in Fig. 1 [10, 11].

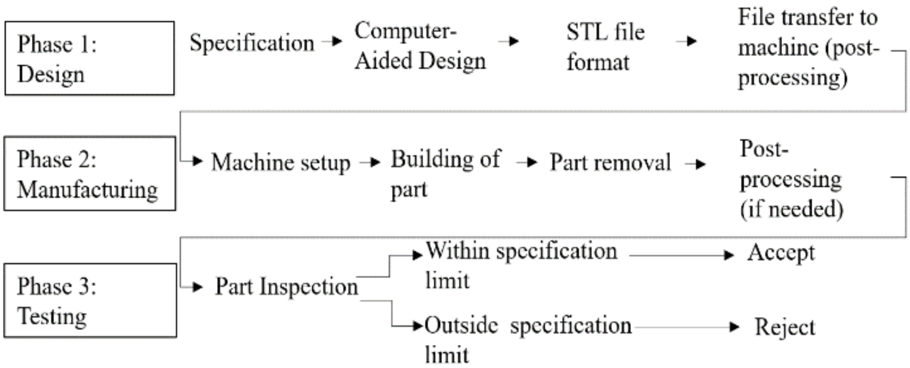

Fig. 1. Phases of Additive Manufacturing

According to Bose and Ke, AM methods are unique in the case when production volume is not extensive, the cost of production is not the biggest concern, but the primary governing factor is to realize what is being designed and its application [8]. Specifically, AM has numerous benefits: it aids production with less waste and scraps, decreases prototyping times and costs, promotes business digitalization, and synthesizes the assembly process into a single part [12]. In the defence industry, AM is perceived as an element of improvement of competitiveness and its potential is widely analysed by European Defence Agency [13].

2.2. Immersive technologies

Immersive technologies, used in many areas of human activity, have a great potential for the development of products of defence industry as well as for defence training. VR can be "an effective assistive tool in the engineering design process, aiding designers in ergonomics studies, data visualization, and manufacturing simulation" [14]. Product development as well as training activity can be performed in a specific type of VR - CAVE Automatic Virtual Environment, which relies on projectors directed from three to six walls of a room-sized cube [15]. The exemplary environment is located at the Immersive 3D Visualization Lab I3DVL of Gdańsk University of Technology in Poland [16]. Engineering companies, both civilian and defence, can use CAVEs to enhance their product development and perform relevant training. Their realism is enhanced not only by appealing graphics but also with sound [17]. The objects viewed through head mounted displays (HMD, VR goggles, VR headsets) can be manipulated or interacted in various modes. Manipulators or gloves with sensors can be used for this purpose (Fig. 2).

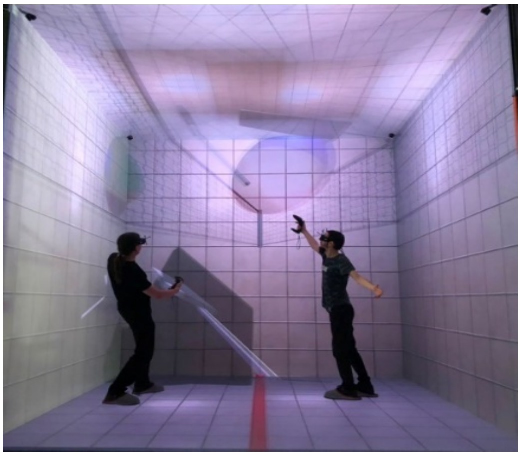

Fig. 2. Example of a CAVE Automatic Virtual Environment (I3DVL archive)

Worth mentioning is the fact that 3D models can be elaborated in smaller CAVEs and then transferred to a midi, or big installation. Other types of technology, such as AR can also support AM; for instance, it can be used while assembling or reassembling an object. Having glasses, additional information, a hint can be displayed on a real object. AR can also help to build digital twin for reconfigurable additive manufacturing system [18]. MR technology, as a blend of physical and virtual worlds, can be used in designing [19], or manufacturing [20] a product; it is also a versatile tool for training [21, 22].

3. USE CASES OF CAVE AUTOMATIC VIRTUAL ENVIRONMENT IN CBRN

One of the infrastructures that aid visualization and prototyping various counterparts and equipment is CAVE Automatic Virtual Environment. It has various applications in the field of CBRN. Newly designed objects can be visualized, or used in different activities, inter alia, training, to check if they fulfil the assumed criteria. The verification can accompany the assessment of rescuers' predispositions in psychological aspects. Thus, in this chapter, we will focus on prototyping, education, training, and even psychological examination as the main assets of this infrastructure.

3.1. Prototyping

Virtual reality is perfect for prototyping both equipment and procedures. The virtual 3D model of the device allows for the detection of many of its drawbacks before the costly production of a physical prototype. By modelling its physics, we can also check its functioning in a wide range (Fig. 3). Scenarios of rescue operations can also be modelled in a similar way.

Fig. 3. Remote control vehicle mobility testing in the CAVE (I3DVL archive)

3.2. Education

Virtual reality has great educational opportunities. Both abstract structures (e.g. the structure of a chemical molecule, Fig. 4) and operational instruments (e.g. the principle of operation of the Geiger-Müller counter) can be shown at low cost.

Fig. 4. Experiments with the protein's structure in the CAVE (I3DVL archive)

3.3. Training

Virtual reality is a safe and relatively cheap training ground for a rescuers exposed to danger (Fig. 5). It helps improve their ability to handle physical threats.

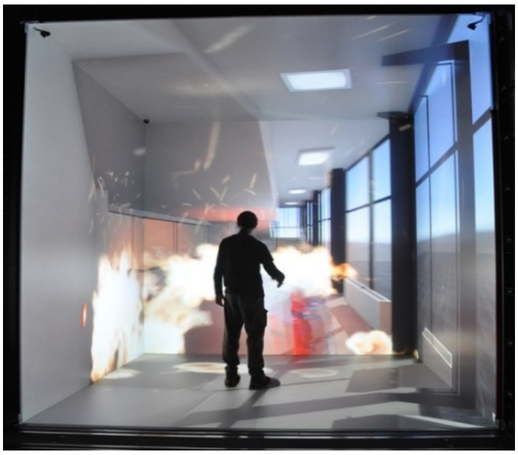

Fig. 5. Firefighting training in the CAVE (I3DVL archive)

3.4. Psychological examination

Immersive environment allows the assessment of human behaviour in various situations, including critical ones. Thanks to this, it is possible to assess the usefulness of a device in an action with a particular scenario. A simulation also enables participants to become accustomed to critical situations (Fig. 6).

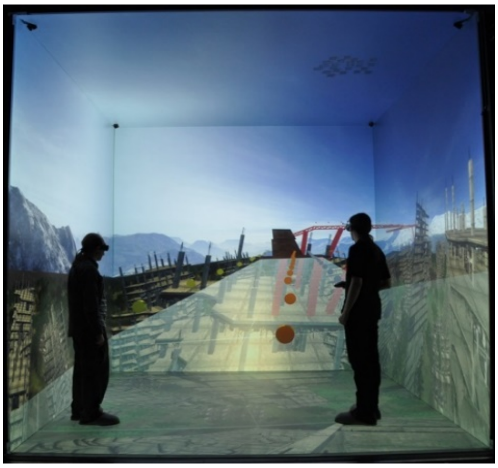

Fig. 6. Assessment of human behaviour in a stressful situation (feeling of high altitude on the glass bridge) in the CAVE (I3DVL archive)

4. IMMERSIVE CBRN TACTICAL TRAINING TO EXAMINE USER EXPERIENCE ON NEWLY-DESIGNED HAND-HELD PRODUCTS

CBRN threats encompass a scope of events such as naturally occurring disasters, accidental incidents at hazardous installations or during the transport of dangerous materials, deliberate incidents, including terrorists' acts and state-sponsored uses [23]. CBRN defence applies to protective measures which are taken in situations of chemical, biological, radiological or nuclear warfare (including terrorism) hazards presence [24, 25]. The counterparts of newly-created equipment for hazards detection, identification, and monitoring, can be modelled and visualized in a 3D environment. The interaction with the counterparts with the haptic gloves may be the first step in the verification of their usability. The second step, after testing in VR, can be printing to use the designed counterparts in prototypes, or as prototypes. Such processes are necessary in Quality Assurance (QA) and Quality Control (QC) standards. One of the ways of verification if the manufactured object fulfils specific requirements, is conducting a virtual training activity. The CBRN defence training [26] can rely on tactic scenarios on preparing and using the device for different techniques of measurements, including its decontamination, and technical servicing. It can be performed in a CAVE Automatic Virtual Environment, which provides numerous advantages for simulations and visualisations.

Such a training usually relies on a combination of fire, technical, and drill training, with the use of combat vehicles. It also entails other military skills, such as decision making, or cooperation, execution of norms concerning the use of equipment, or the measurements of CBRN contamination level. The tactics vary depending on the contamination type (chemical, or biological). After the tactic mission, the combat readiness is restored and the task completion is reported. Such a training will be helpful in user experience research, especially, when a device is being enhanced and other new functionalities are developed.

It is vital to stress that thanks to immersive technologies it is possible to visualize any type of hazards, their removal [27, 28], or conduct specific chemical processes [29-32]. For instance, the dose rate in a radioactive area can be marked with different colours. As the dose rate can be simulated, it can be measured with a newly-designed device (as a 3D object, easy to manipulate). Then a soldier has to decide whether the task should continue or not due to the high radiation level.

After printing, a training in a field can be conducted where ergonomy, material (durability), overall functioning can also be tested. Such a training can also be enhanced with AR and MR. Having goggles, additional information can be displayed about the real-life object, or an additional object can be explored and interacted. After positive tests and certification of the CBRN recon device, tactical training can be performed.

When deciding whether to print 3D elements of a system, 3D modelling is an integral part of the manufacturing phase. In VR, it could be possible to interact with designed functionalities to assess if they work well or if they are intuitive for future users. As the some CBRN projects assume a training session with a newly developed tool, 3D models can be prepared and then printed in small series to check if the equipment is handy, intuitive, and easy to use. Different experimental conditions may trigger changes in the final version of the product.

5. CONCLUSION

Immersive technologies enhance AM processes in the way that they can be tested in the design phase, and after their manufacturing, other functionalities can be developed. In the testing of printed CBRN recon devices, counterparts, relevant data can be gathered to improve the quality of the product.

Data on Errors Related to a Designing Process

Functionality tests performed in a virtual environment help in early detection of errors related to counterparts of an equipment. Fixing and improvements of the products saves time and cost related to its further development.

Data on Users' Experience

Any training session can be treated as a source of information on the product. Therefore, after the certification processes of the CBRN device, different opinions on experience with the device can be gathered. They will serve for further product development or its functionalities enhancement.

Notably, the contemporary civilization associated with challenges for security and safety [33, 34] requires the development of solutions which will provide quick and prompt data about a specific situation. The visualization of specific counterparts results in not only faster development of innovations, but also ensure their proper, ease, and better functioning. Various innovative products or processes can be enhanced, facilitated, and intensified. Within the framework of dedicated methodologies, for instance agile or cascade, they can be easily created [35-37]. In these circumstances creativity together with interdisciplinary cooperation plays a significant role in innovations development. The contemporary endeavours pave the way for a stronger civilian and military industries' integration, which should be based on shared experiences, projects and focus on the improvement of defence studies and technology capabilities at both national and international levels [38]. It is especially important in the field of CBRN, where interoperability is the key factor in mitigation of the effects of CBRN incidents.

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