Результати розрахунків виводяться у табличному вигляді та можуть бути збережені у форматі HTML або передані до пакетів Microsoft Word, Microsoft Excel.

Висновки та напрямки подальших досліджень. У якості інструментарію з розробки програмного забезпечення вибрано мову С++ на базі бібліотеки MFC інтегрованого середовища Microsoft Visual Studio 2019. Для обробки баз даних використано технологію ADO, для роботи з 3D-графікою – відкриту графічну бібліотеку OpenGL [7-10]. Крім того, розроблено 3D-модуль аналізу кожного вузла сітки відносно найближчих кернів свердловин та організоване поповнення результуючої інформації по довільним профілям кар'єру, які задаються двома параметрами: відстань між профілями та кут нахилу. Це дає можливість порівняти результати при різних параметрах кутів та відстані між профілями та оцінити отримані результати.

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THE ANALYSIS OF WORKING ENVIRONMENT IN OPERATION OF 3D PRINTERS FOR FUSED DEPOSITION MODELLING

Purpose. The creation of safe working environment and the overall environmental footprint of 3D printing process is the relevant issue for the industry and other fields of human activity. The urgency of the research is due to the need to explore the working environment in operation of 3D printers for fused deposition modelling technology (FDM) as one of the most wide-spread.

Research methods. General theoretical methods (analysis, generalization, synthesis) are used in the study.

Scientific novelty. A comprehensive analytical study of occupational safety of 3D printing as a manufacturing process of processing materials was carried out. It reveals that despite of the digital focus of 3D printing, it is a mistake to apply to it the requirements of safety related only to digital technologies. The negative effects of the equipment for FDM-based 3D printing are of low intensity, bit under condition of long-term impact they can have a cumulative effect.

Practical significance. The study identifies hazardous and harmful factors of working environment and the labor process, generated in FDM-based 3D printing with two of the most common type of plastic: ABS and PLA. Harmful chemicals emitted during the printing process by these plastics and their effects are considered. The means of collective protection both for the professional operators and for surrounding persons are suggested.

Results. Hazardous and harmful production factors inherent in fused deposition modelling technology as a method for processing materials were considered. The preference of using PLA plastic for 3D printing in the non-production sphere is substantiated. The suggestions on occupational safety to optimize working environment for FDM-based 3D printing are represented.

Key words: 3D printing, fused deposition modelling, ABS plastic, PLA plastic, occupational safety, working environment, hazardous and harmful production factors, harmful chemicals

The technology of 3D printing is the newest and rapidly developed among the additive technologies used for parts and objects manufacturing. This technology was invented in the mid-80's of the last century, its introduction into everyday practice began by the mid-2000s, and nowadays it has a wide application in various fields of human activity. 3D printing is a generic name of the group of information-based technologies of material treatment. These technologies rely on digital designing of three-dimensional objects and their further layer-by-layer reproducing using special numerical controlled equipment which is conventionally called 3D printers.

The main advantages of 3D printing in comparison with the classical material processing methods are the decrease in level of environmental pollution by minimizing the amount of industrial waste and the reduction of energy consumption of technological equipment. The relevance of the study is due to the fact that 3D printing is placed at the intersection of industrial technologies and the industry of knowledge. As a matter of fact, any industrial production is the processing of large amounts of raw materials and the functioning of technological equipment in different manufacturing processes. Regarding the industry of knowledge – Information Technology – the main its value is the human as the creator of certain methodologies and software products. That's why health preservation as well as increase efficiency and productivity of both individual employee and the team are the main objectives of every company or organization.

Problem and its connection with scientific and practical tasks. The development of 3D printing occurs in three main directions. The first direction is a search for new materials, which can be used for prototyping for already known technologies. The second direction is a search for new 3D printing technologies and a hardware for their implementation. The third direction is a development of software necessary to implement different 3D printing technologies with different materials. The studies in these areas also involve some specific safety issues, for example, the biological compatibility of implant printing materials [1, 2]. However, much of these studies are fragmented and incomplete, because they are considering certain aspects of safety, usually related to the quality of the printed product or with its influence on a human organism during exploitation.

A comprehensive study of occupational and ecological safety of 3D printing as the technological process of processing material is needed. Such a study should be carried out as the analysis of hazardous and harmful factors of production environment and labor process. Guidelines on occupational safety and health as well as recommendations on environmental protection should be based on such a study.

Analysis of recent achievements and publications. 3D printing technologies are characterized by a variety of manufacturing principles and, as a result, they are characterized by a variety of equipment and materials used for prototyping. Currently, Fused Deposition Modelling (FDM) technology is the easiest to implement and the most widespread. Its basic principle is the sequential formation of layers of printed item of a rigid polymer, which is fed into the printing area in the form of heated wire. The range of the materials used for 3D printing is rather small, it has about a hundred items [3]. Most materials can be attributed to three main groups: polymers, metals and ceramics [4]. Organic substances such as tissue cells, cellulose or foodstuffs are used for the specific types of 3D printing [5].

Industry, medicine, education – these are the areas of human activity in which 3D printing is considered to be an important and current technology. Each of these areas makes specific demands for 3D printing products. The accuracy and strength characteristics of finished item determine the choice of technology and materials for 3D printing in electronic and aerospace industry, in mechanical engineering and automotive industry [6 – 8]. Finished item for regenerative medicine, orthopedics, cardiology, dentistry should meet the requirements of manufacturing accuracy together with biological compatibility of materials [9, 10]. In the field of education 3D printers are considered to be an effective training tool in engineering and natural sciences. The use of 3D printers in secondary and higher educational institutions demands first of all to ensure the safety of students [11]. However, the comprehensive multilateral studies on this issue are lacking. Investigators usually focus on the realism and visibility of printed three-dimensional training models or on the level of difficulty in obtaining competence in 3D design and 3D printing [12, 13]. A number of studies are devoted to the social aspects of 3D printing applications: as a therapeutic tool or as a tool for food security achievement [5, 14, 15]. Also noteworthy is the problem of hazardous or prohibited items printing, such as weapons [12], but issues like this are more in the realm of social and ethical security.

Safety analysis of 3D printing focuses on improving the safety of materials, assessing their impact on human beings and the environment. For example, the main objective of printed medical items is to achieve material biocompatibility considering kinetics of decomposition, minimization of decomposition by-products and other negative effects [4, 16]. 3D printing has a significant potential as a way to reduce the carbon footprint of industrial production [15]. The pressing problem for 3D printing is the product and waste management [17, 18].

Relatively low energy consumption is an advantage of all 3D printing technologies compared to the classical material processing methods. The consequence of this is the lower intensity of hazardous and harmful production factors affecting the operator. Perhaps this is the reason for the low attention paid to the industrial safety issues of 3D printing. However, 3D printers are not absolutely safe in terms of occupational health and safety. Whether in industry, in educational and medical institutions or at home, 3D printers generate factors which are hazardous and harmful to human beings.

The factor which draws attention to the majority of researchers is air pollution in 3D printer working environment. The most obvious effect of printing process is the emission of harmful substances into the air, namely, particulate matter (including ultrafine particles 1 – 3 nm or less), toxic gases and volatile organic compounds [3, 11, 15]. There is a number of studies on air pollution while 3D printing, but authors usually focus on the chemical composition and the intensity of pollution without taking into account the duration of 3D printer users exposure to harmful substances [19].

Some authors consider the problem of vibrations during 3D printing, but the studies are devoted to the impact of vibrations on the quality of a printed product, and do not address the problem of the impact of vibrations on the human operator [20].

The paper [11] emphasize the need for risk assessment and conducting research devoted to additive technologies, with special attention to toxicological and environmental hazards that may arise in production, use and disposal of printed objects, raw materials and waste. As an illustration of an unexpected negative event, the exploitation of 3D printers in educational institutions is considered. So, here the problem is that students, sensitive to air quality, may be inadvertently exposed to harmful substances emitted in 3D printing. For example, in [21] it was shown that 12 volatile organic compounds with concentrations below the recommended limits were detected during 3D printers operating. But according to the authors, the results obtained do not reflect all possible impact scenarios and further research is needed to detect the level of impact and effectiveness of manufacturing process monitoring.

Statement of the problem. Thus, we see that the aspects of production safety of 3D printing have not been duly studied and documented. There is a compelling need for the research of working environment of the process of object manufacturing by 3D printing. The purpose of the research is to identify hazardous and harmful production factors and assess their levels for further occupational risk reduction. The result will be the ability to ensure safe and eco-friendly working environment for 3D printer professional users; as well as the ability to ensure reduction of threats to the health of non-professional users and the development of safer practices of 3D printers using for non-industrial activities. Fused Deposition Modelling (FDM) technology is selected as the research object, which is the most common due to its accessibility and efficiency.

Presentation of the main material and results. Because of its belonging to digital technologies, working environment of 3D printing process can be characterized by hazardous and harmful production factors, typical for all computer-related activities. The main ones are: the danger of electric shock, the lack of natural daylight and insufficient lightning of the working area, poor indoor climate parameters in working premises. Computer monitors create such harmful factors as increased light brightness, increased light flux pulsation, reduced contrast of images and symbols. The overloading of visual analyzer, the static overloading of locomotor system, the dynamic overloading of upper limbs are typical psychophysiological harmful factors. In addition, as it always been in creative activity, there are mental overstrain and the emotional overload. Protection from hazardous and harmful production factors listed above is carried out with regard to the requirements of regulations.

All the computing hardware is characterized by the high level of high-frequency noise generated in ventilation systems. But in this regard, 3D printing has certain features. Rotary units and reciprocating units of 3D printers generate low-frequency noise and vibration. These include cooling fans of extruder and power supply, stepper motors, linear bearings together with printer cases, that vibrate during printing. The actual noise and vibration levels depend on the materials and design of printer housing, the type of motors and fans, the materials of drive structural elements. The best solutions to reduce noise and vibrations are: printer setting on anti-vibration supports, the use of software for intelligent fan speed control and intelligent stepper motors control, the acoustic treatment of production facilities.

Air pollution with toxic gases and particulate matter is the harmful factor of 3D printing that attracts significant attention of most researchers. Manufacturing of an object on FDM technology consists of heating and melting the filament (polymeric raw material in wire form) and layer-by-layer forming of pre-designed item. Two types of polymeric raw material are most commonly used for 3D printing: they are ABS and PLA plastics. All the filaments are the consumables and they are safe when storing, as any polymer in the solid state. But when the polymers are heated and melted, their thermal destruction (degradation) occurs and the new substances are formed during the oxidative reactions by interaction with oxygen in the air. As a result, the fumes of polymer source components or the fumes of polymer thermal-degradation products are emitted into the workplace air.

ABS polymer (acrylonithrylbutadienstyrene) is the solid opaque copolymer thermoplastic material, produced from three source monomers: acrylonitrile, butadiene 1,3 and styrene. In turn, these three source components are petroleum-based products, so they are highly toxic when heated.

Acrylonitrile, also known as vinyl cyanide, is colorless toxic volatile liquid, which has the faint odor of bitter almonds. Acrylonitrile classified as High Risk substance, it is a potent toxicant, in small doses it has a carcinogenic effect. It enters the human body through the respiratory tract and intact skin, its toxic effect is similar to that of cyanides. When ingested, depending on the volume of the absorbed substance, causes headache, nausea, vomiting, dizziness, sleep disorders, general fatigue.

Styrene is colorless, toxic, volatile liquid with a sharp and unpleasant odor similar to that of alcohol or acetone. It is classified as Moderate Risk substance. It belongs to the category of substances of general toxic action with an irritant, mutagenic and carcinogenic effect. Styrene enters the human body by breathing in, causing irritation of the mucous membranes, disorders of the nervous system and the hematopoietic system, disorder of digestive tract, as well as chronic kidney and liver diseases.

Butadiene is heavy gas with unpleasant odor, it easily interacts with atmospheric oxygen, forming peroxide compounds. It is classified as Low Risk substance. It has general toxic action with an irritant, neurotoxic and carcinogenic effect. In high concentrations butadiene suppresses the nervous system, there may also be respiratory disorders and loss of consciousness. With long-term exposure it is a carcinogen; it can affect bone marrow and liver, it can cause hereditary and genetic disorders.

Also in printing with ABS plastic benzene emission was fixed [21]. Benzene is a High Risk toxic substance, it affects the central nervous and hematopoietic systems, has a carcinogenic and mutagenic effects. At low doses benzene causes chronic poisoning whose early symptoms are headaches and dizziness, irritability, increased fatigue, a general malaise, bleeding gums and retinal hemorrhage.

PLA polymer (polylactic acid) or polylactide is a fully biodegradable thermoplastic polyether based on lactic acid. PLA belongs to a group of polyesters. It is obtained through synthesis of vegetable raw materials, containing starch or sugar, obtained after the processing such plants as corn, potatoes or sugar cane. Since natural ingredients are used for the production of PLA, it is considered to be safe for human health when heated and melted. However, during PLA melting lactide and acetone are emitted. Lactide is harmless to the human and is not capable to cause dysfunction of body systems. Acetone is toxic, colorless, volatile liquid with a characteristic odor. It is classified as Low Risk substance. Acetone fumes enter the human body by breathing in. Acetone irritates the mucous membranes of the eyes and respiratory tract, symptoms of its impact are sore throat and cough, eye pain and blurred vision, nausea, vomiting, dizziness. In high concentrations or in a particularly sensitive person (children especially) it has a narcotic effect and can cause clouding and loss of consciousness.

It has been determined that contamination with volatile organic compounds in ABS printing is more intense than in PLA printing [21]. In addition to the volatile organic compounds, carbon dioxide, carbon monoxide, nitrogen oxides (NO_x) as well as halocarbons (CFC, HCFC, CCl_4), trichloroethane, nickel and lead compounds are generated in 3D printing process [13].

In addition to the toxic substances in vapor and gas phase, 3D printing generates ultrafine polymer particles, increasing the particulate air pollution in the working premises. Ultrafine particles enter the respiratory system with air flow and penetrate directly into the mucous membranes of the respiratory tract and the alveoli of the lungs, causing allergic reactions and respiratory diseases.

The ABS printing process generates an average of 200 million ultrafine particles per minute. For PLA plastic this rate is an order of magnitude smaller: about 20 million ultrafine particles per minute. The size of particles generated by ABS printing is smaller than in PLA printing. That means a greater degree of their penetration through the respiratory system, as well as through the skin, and therefore, a greater intensity of their participation in the metabolism [21, 22]. Therefore, PLA plastic is more safe than ABS, but it also requires air purification. That’s why it is recommended to set up dust trapping and air ventilation for all the premises in which 3D printers are located. Furthermore, for industrial 3D printing environment, the staff must use protective clothes and protective equipment such as gloves, goggles and masks [15, 21]. However, personal protective equipment can cause physiological discomfort and is quite justified only in industrial environments. The removal of pollutants directly from the place of their generation is the most effective measure both for industrial and non-industrial working environment. This can be achieved by operating 3D printers with closed or hermetically sealed cases equipped with integrated HEPA filters. The local exhaust ventilation devices equipped with HEPA filters for air filtration in the vicinity of the printer are the effective protective measure too. In this way gas and ultrafine particles can be filtered efficiently.

The design of any 3D printer provides a significant number of mobile units and elements that can cause mechanical injury: drives, pulleys, threaded screws, timing belts, extruders, fans, movable tables-platforms. 3D printers used in non-industrial applications usually do not pose a significant threat to human operator, but in industrial environments the injures with quite severe consequences are possible.

During printing and immediately after it some surfaces of printing unit, of the filament in printing zone and of the finished item have a fairly high temperature. The design of FDM printer provides two heating elements: the extruder and the work platform. In printing process the temperature of extruder nozzle varies from 170 to 300 ºC depending on the type of plastic and configuration of printed item. Operating temperature of the work platform must be within 50 – 80 ºC. At various conditions ABS plastic melting point is 210 – 270 ºC, PLA plastic melting point is 190 – 230 ºC. Touching the extruder nozzle or the work platform or the workpiece during printing can lead to burns of skin and subcutaneous tissue. Safety requirements for printer operation and maintenance are developed to prevent injury. Since the working temperature of the printing unit is 50 – 300 ºC, there is the emission of sensible heat in the premise, which leads to the workplace air heating. Printer design provides fans for cooling the printing area, which create streams of hot air. Therefore, the necessary condition for the premises where 3D printers are located is the normalization of microclimate parameters by using general ventilation.

Conclusions and direction for the further research. The analytical study of working environment and labor process for FDM-based 3D printing identifies the following hazardous and harmful production factors that can cause injury to the equipment operator:

the movable units of 3D printer can cause mechanical injury;

the increased temperature of extruder and the work platform surfaces, of the filament in printing zone and of the finished item; contact with these surfaces can cause burns.

The following harmful factors of production environment affecting the health of human operator and the health of those who occupy it arise in the premises where 3D printers are located:

the increased air pollution by volatile organic compounds;
the increased air pollution by ultrafine polymer particulate matter;
the increased level of low frequency noise and vibration;
the increased temperature of the workplace air because of the emission of sensible heat.

Therefore, despite of the digital-orientation of 3D printing, it would be a mistake to apply safety requirements related only to digital technologies. The negative impacts of FDM-based 3D printing equipment are of low intensity, but they may have a cumulative effect under long-term settings.

Over the next period of the research it is planned to examine the visual work conditions of 3D printer operators in more depth. Of interest are physical and psychophysiological factors of production environment, related to the lightning in a workplace of 3D printer operator.

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ЗАСТОСУВАННЯ МЕТОДУ ДИНАМІЧНОГО ПРОГРАМУВАННЯ ПРИ ВИКОНАННІ МАГІСТЕРСЬКИХ КВАЛІФІКАЦІЙНИХ РОБІТ З ЕКОНОМІКИ

Мета. Підвищення якості підготовки магістрів з економіки в системі вищої освіти ґрунтується не тільки на глибокому засвоєнні фахових, але й фундаментальних дисциплін. Саме практичне застосування набутих знань з математичного програмування при виконанні кваліфікаційних робіт з економіки дозволяє вирішувати конкретні виробничі завдання в умовах невизначеності та ризику прийняття рішень. Тому вільне володіння оптимізаційними методами, зокрема методом динамічного програмування, є необхідною передумовою досягнення поставленої мети.

Методи дослідження. В статті використана багаторівнева методологія пізнання за рівнем загальності, а саме загальнонаукові та часткові методи наук. Зокрема, при аналізі сучасних наукових напрацювань з проблеми застосування оптимізаційних методів використані методи аналізу і узагальнення. Методи емпіричного дослідження використано при встановленні взаємозв'язків між показниками виробничо-господарської діяльності суб'єктів господарювання і параметрами функціонування їх структурних підрозділів. Методи оптимізації застосовано при розробці найбільш ефективної програми відновлення та заміни екскаваторного парку, при розподілі інвестицій у розвиток підприємства та при розподілі заохочувального фонду стимулювання робітників цеху технологічного автотранспорту.

Наукова новизна досліджень полягає у поширенні уявлень про області застосування методу динамічного програмування з вирішення прикладних завдань при підготовці магістрів з економіки і виконанні кваліфікаційних робіт.

Практична значимість результатів дослідження, викладених у статті, полягає у посиленні фахових компетентностей, які набувають магістри в процесі навчання і виконання кваліфікаційної роботи. Ці компетентності дозволяють ставити та вирішувати конкретні виробничі завдання з використанням методів динамічного програмування, що в сучасних умовах виробничої та економічної діяльності підприємств є актуальними. Важливим елементом є можливість впровадження результатів дослідження у діяльність базових підприємств гірничо-металургійного комплексу, які є системоутворюючими і у значній мірі формують регіональний та державний бюджети.

Результати. Сутність одержаних результатів полягає у кваліфікаційній складовій підготовки магістрів з економіки і виробничій, де вони можуть самореалізуватися і показати вміння застосовувати одержані знання і навички з оптимізації та оцінки виробничих завдань з найбільшою ефективністю.

Ключові слова: економіка, магістрант, кваліфікаційна робота, економіко-математичне моделювання, динамічне програмування, ефективність.

Проблема та її зв'язок з науковими і практичними завданнями. Оцінка якості підготовки фахівців за другим освітньо-професійним рівнем вищої освіти «магістр» відбувається за результатами виконання на високому науково-методологічному та методичному рівнях кваліфікаційної роботи і подальшого її захисту. Магістерська робота є концентрованим вираженням результатів попередньої поточної успішності в рамках всієї системи одержаних за період навчання знань і практичних навичок. Зокрема, підготовка магістрів спеціальності 051 «Економіка» спрямована на набуття ряду компетентностей, опанування якими дозволяє досягнути інтегральної у формулюванні: «Здатність визначати та розв'язувати складні економічні задачі та проблеми, приймати відповідні аналітичні та управлінські рішення у сфері економіки або у процесі навчання, що передбачає проведення досліджень та/або здійснення інновацій за невизначених умов і вимог» [1, с. 6]. Зазначене вище надає можливість формулювати конкретні «професійні задачі в сфері економіки та розв'язувати їх, обираючи належні напрями і відповідні методи для їх розв'язання, беручи до уваги наявні ресурси» [1, с. 7]. Для сучасного фахівця окрім постановки і визначення напрямків вирішення проблемного завдання, більш нагальною задачею є знаходження оптимально-ефективного варіанту вирішення поставленого завдання. Досягнення зазначеної мети неможливе