Usage of additive technologies in the Arctic region

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Abstract. The article considers the use of additive technologies in the Arctic region as a tool that contributes to the sustainable development of the Arctic territories. The Arctic region is rich in deposits of minerals, hydrocarbons and other strategically important resources for the Russian Federation. In the article described the current use of additive technologies and a classification of additive technologies according to the following criteria: method of layer formation, method of the powder conversion and on the materials being processed. The types of additive technologies for each classification criterion are considered. A conceptual approach of analyzing the capabilities of additive technologies in the Arctic is proposed, it is based on the classification of the Russian Arctic area into subspaces and consideration of the capabilities of additive technologies for each subspace. Due to the fact that human activity in the Arctic is heterogeneous, the entire region can be divided into subspaces for functional purposes. The article presents the results of the analysis of the possibility of using additive technologies in the following Arctic subspaces: base cities, mobile rotational camps, mineral resource extraction territories, recreational territories, fishing territories, the Northern sea route, and infrastructure for the protection of safe existence. The article describes the application of additive technologies taking into account the functional features of each subspace of the region, describes advantages and limitations of using this technology of its use.

1. Introduction
This article considers the integration of modern technologies in the Arctic region in order to increase its productivity. The Arctic region was chosen as an object of additive technologies deployment due to the strategic importance of the territory [1], [2], [3], [4], the need for more efficient use of resources [5], [6], [7], [8], [9], and the necessity to choose directions of sustainable development for various subjects of this territory [10], [11], [12], [13], [14].

The introduction of modern technologies of the fourth industrial revolution is an impetus for economic, social, scientific, technical and environmental development. High-tech equipment provides economic efficiency, high productivity and competitive advantage in any industry.

The purpose of this article is to review the existing types of additive technologies, develop a classification for their application in the target subspaces of the Arctic region of Russia, and present a conceptual approach of analyzing the possibilities of additive technologies usage in the Arctic.

2. Current state of additive technologies use
Harsh Arctic conditions: temperatures up to -60 degrees, salt water, high humidity, Arctic winds and low solar energy supply make it difficult for people to work in this area. However, the extremely rich resource potential of the region has pushed humanity to develop it. The region contains vast deposits of hydrocarbons (oil, natural gas, gas condensate), deposits of precious, rare earth and non — ferrous...
metals—gold, nickel, copper, tungsten, uranium, platinum, palladium, molybdenum and others, diamonds, coal and fresh water reserves.

According to the UN Convention on the law of the sea of 1982, the Arctic region is divided into 5 parts between Russia, Canada, the United States, Norway and Denmark. Moreover, 43 % is the Russian sector which accounts for 40 % of all Arctic oil reserves and 70 % of natural gas reserves. That makes the Arctic a strategically important region for the Russian Federation.

Russian organizations involved in the development of the Arctic shelf actively collaborated with international companies with advanced technological developments and work experience in the Arctic until 2014. However, due to the introduction of sanctions most projects were suspended, for example, cooperation with ExxonMobil, Statoil and other high-tech companies. In the context of limited opportunities for cooperation with foreign companies to develop the Arctic shelf, import substitution of high-tech equipment that has fallen under the ban of anti-Russian sanctions should contribute to the development of the Arctic shelf.

The fourth industrial revolution gave rise to the development of a new method of production—additive manufacturing. Additive manufacturing concentrates the advantages of modern production technologies and information systems for the development of production capabilities [15]. Additive manufacturing is a high-tech way to combine and synthesize materials to create objects based on three-dimensional information models. Additive manufacturing technologies over the past ten years have received a significant momentum in development. Every year there are more cases of their successful use in various industrial applications [16]. Russian organizations, including Peter the Great University of Saint Petersburg, are already actively using the capabilities of additive technologies in their activities and are conducting research to expand the potential of this technology.

In this article, the main types of additive technologies will be considered and a classification of their application in various parts of the Arctic, taking into accounts their characteristics and conditions will be proposed.

Charles Hull developed the world’s first 3D printer in 1983. It worked based on additive technology, which is known as the process of stereolithography (SL). The first SLA and SLS machines were relatively expensive and could only work with a limited range of materials, but in the process of technological development the capabilities of additive manufacturing have expanded significantly and become more accessible for use.

Additive technologies can be classified according to the following criteria: the method of forming a layer, the method of conversion of the powder and the materials being processed.

According to the methods of layer formation, there are two types of additive technologies: Bed Deposit and Direct Deposit. Bed Deposition assumes that the material is applied evenly to the entire surface of the platform, and then material is selectively sintered along the path specified by the CAD model by a laser or other method. Specific is that the platform remains stationary. Direct Deposit assumes that the material is fed directly to the processing area.

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The following technologies are used for material transformation into a CAD-model-defined object:

1. Material Extrusion is a technology for obtaining products by pushing the material through the forming hole;
2. Directed Melting Deposition assumes that the material is fed through a spray gun to the heated product, fused on it and forms a smooth coating;
3. VAT Photopolymerisation (stereolithography) is a solidification of polymers by ultraviolet radiation;
4. Sheet Lamination is a gradual bonding of the sheet material with the subsequent formation of the outline by laser cutting;
5. Powder Bed Fusion is a melting of the powder using laser beam.

Polymers, metals and their alloys, ceramics, sandstone, resins, paraffin and composites of these materials are used for the production of objects using additive technologies.

3. A conceptual approach of additive technologies use analyzing in the Arctic
The conceptual basis for analyzing the capabilities of additive technologies in the Arctic is the classification of the Russian Arctic space into subspaces and consideration of the capabilities of additive technologies for each subspace. The following subspaces were selected as subspaces of the Arctic zone: base cities, mobile rotational camps, mineral resource extraction territories, recreational territories, fishing territories, the Northern sea route, and infrastructure for the protection of safe existence [1], [17].

Methods of analysis and synthesis, methods of expert assessments, methods of comparative economic analysis allow us to consider the possibilities of additive technologies for each subspace.

4. Results
Current level of development of additive technologies demonstrates that installations which use additive manufacturing technologies have practically no restrictions in the geometry of manufactured products, which makes it possible to optimize them most effectively. Despite that fact complexity does not affect the speed of manufacturing parts. For example, the production of complex parts and components of aerospace engines, such as turbine blades, combustion chambers, etc. with the use of additive technologies is reduced from a few weeks-months to a few hours-days, which in turn leads to obvious economic benefits. These technologies lead to a revolution in the design, manufacture, and delivery of products, as well as affect the entire product lifecycle.

The following advantages are realized in the production process, in contrast to mechanical processing, casting, and so on:
1. Additive manufacturing reduces the production chain to creating a digital model – uploading the model to a 3D printer – printing. In addition, some additive technologies produce a finished product that does not need post-processing;
2. Additive manufacturing simplifies logistics at the enterprise, since it does not need a conveyor and does not involve a significant number of production operations;
3. Additive manufacturing requires less raw material costs, since the printing process consumes exactly as much raw material as is used in the finished product. An exception may be additive technologies that require supports for printing, but even in this case, the raw material costs do not exceed the costs of production using traditional methods;
4. A single operator is required to maintain the 3D printer. Means that a single specialist handles the entire production life cycle of the product;
5. Using the additive manufacturing an object can be customized at the 3D model stage;
6. Additive manufacturing improves the quality characteristics of the product, as it does not form joints and connections, getting a single finished object;
7. There is no need to store spare parts of the manufactured object, since the 3D printer produces it as a single object.

Thus, the benefits of using additive technologies in the Arctic region are obvious. However, there are a number of restrictions that may prevent AM implementation in the harsh Arctic conditions. Therefore, it is necessary to classify additive technologies taking into account the characteristics of the Arctic subspaces.
Classification considers the following restrictions:
1. The temperature can reach -40 to -60 degrees across the Arctic;
2. The region has the highest level of humidity in Russia, which can reach 95%;
3. Subspaces such as fishing territories and the Northern sea route, imply the use of vessels, therefore, the use of certain additive technologies on them may not be possible, since the motion instability will lead to a violation of the surface layer integrity;
4. Some of the 3D-printer may not be possible to install due to their large size;
5. The use of technologies that produce products from non-cold-resistant and corrosion-prone materials may be impractical in Arctic conditions.

Given these limitations, the following conclusions can be drawn for each of the additive technologies:
1. Material Extrusion can be used commonly. The accuracy of printing decreases on mobile objects, however, items produced by this method will have stable mechanical properties. 3D-printers that use this technology are the cheapest and least dimensional (less than 1×1×1 m), and the products produced by AM have the widest application horizons.

This type of technology can be used to create models for testing, prototyping, and rapid small-scale production. Metal powder and thermoplastics are used for manufacturing objects in Material Extrusion. Most of thermoplastics have fireproof properties, which makes them suitable for use in aircraft construction. There is the following extrusion method – FDM;

2. Directed Melting Deposition technology is not very whimsical to the environment, but it assumes a static installation and has a relatively large size. If this technology is used on a moving object, the material may not be accurately sprayed thus distorting the geometry of the final product.

This type of technology can be used to repair or add additional material to existing components. This method uses gypsum, plastics, metal powders, and sand mixtures to produce objects. There are the following methods of jet deposition – DMD, DLMD;

3. Stereolithography is not suitable for Arctic conditions due to the fact that photopolymer resin is whimsical to the environment. A special room with a certain temperature (≈25 degrees) and humidity (≈15%) is necessary for use of this technology. In addition, stereolithography assumes static usage due to the high probability of breaking the integrity of the surface layer of the print on mobile objects.

This technology is characterized by high accuracy and can be used to create complex products. For manufacturing by stereolithography photopolymer resin is used. There are the following methods of stereolithography – SLA, SL, DLP, DLS, LCD, CLIP;

4. Sheet Lamination can be used in any conditions. This method is most suitable for use on mobile objects.

Sheet Lamination produce objects with mechanical characteristics below average that is why it can be used to produce blanks for casting and layouts. Products manufactured using this method have a low cost.

This method uses paper, metal foil, and polymer film to make objects. There is the following lamination method – LOM;

5. Powder Bed Fusion involves a powder bed, which can deform when the unit is not static. 3D-printers using such a technologies have large dimensions.

The technology allows to create hollow metal structures of high geometric complexity. The method is used in industry as it provide possibility to optimize manufactured objects, reduce their production time and get significant economic benefits in small-scale production.

This method uses metals and their alloys, ceramics, and thermoplastics to make objects. There are the following methods of layer-by-layer growing: SIBM, SLM, SLS, DMLS, EBM, PBF.

The following areas of use of 3D printers in the Arctic zone can be identified:

1. The use of 3D printers in industry for manufacturing components of icebreakers, ships, helicopters, oil platforms, and other equipment used in the Arctic, as well as for the production of consumer goods. For example, a 3D printer can produce drainage filters, screw pins, turbine engine blades, bearing housings, combustion chambers, box heat exchangers, and ship propellers based on local needs.

2. Additive technologies can be used in medicine to produce prosthetics;

3. Use of 3D printers as auxiliary equipment on Arctic vessels, oil platforms, etc. for emergency reproduction of their components and spare parts that are not stored on the ship or are difficult to access, due to the remoteness from the mainland, stormy weather conditions and ice hindering movement;

4. Use of 3D printers on Arctic vessels, oil platforms, etc. for their repair and maintenance by applying additional layers of material to the deformed or worn component, thus eliminating the need to replace it;

5. Use of 3D printers in R&d;

6. Use of AM for prototyping, building layouts, and test samples.
Table 1 provides a classification of additive technologies for possible applications in Arctic subspaces.

**Table 1. Classification of additive technologies by possible use in Arctic subspaces**

| Subspace                             | Features                                                                 | Suitable additive technologies                                                                 | Usage area                                                                                           |
|--------------------------------------|--------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|
| Base cities                          | - Settlement of at least one thousand people;                            | - Material Extrusion – FDM; - Directed Melting Deposition – DMD, DLMD; - Sheet Lamination – LOM, UAM; | - For R&D; - Industrial production in the field of shipbuilding, aircraft construction, mechanical engineering, medicine, construction; - Production of consumer goods; - Prototyping, building layouts and test samples. |
|                                      | - Includes industrial organizations, infrastructure, medical, cultural, and administrative facilities; | - Powder Bed Fusion – SIBM, SLM, SLS, DMLS, EBM, PBF.                                             |-------------------------------------------------------------------------------------------------------|
|                                      | - Temperature up to -40; - Humidity up to 93%;                          |                                                                                                    |-------------------------------------------------------------------------------------------------------|
|                                      | - It is possible to create acceptable humidity, temperature and static conditions for the 3D printer work. |                                                                                                    |-------------------------------------------------------------------------------------------------------|
| Mobile rotational camp               | - Temporary nature of the camp for the purpose of servicing various projects; - No infrastructure; - Population less than a thousand people; - Temperature up to -40; - Humidity up to 93%; - It is possible to create static conditions for the 3D printer. | - Material Extrusion – FDM; - Directed Melting Deposition – DMD, DLMD; - Sheet Lamination – LOM, UAM. | - Printing small items; - Repair of deformed items; - Production of consumer goods; - Construction of temporary facilities; - Prototyping, building layouts and test samples. |
| Mineral resource extraction territories | - Territories of deposits and facilities serving them; - Temporary nature of facilities until the field is depleted; - Temperature up to -60; - Humidity up to 93%; - It is possible to create static conditions for the 3D printer. | - Material Extrusion – FDM; - Directed Melting Deposition – DMD, DLMD; - Sheet Lamination – LOM, UAM. | - Printing small items; - Repair of deformed items; - Prototyping, building layouts and test samples. |
| Recreational territories             | - Reserves and national parks, zones of various types of tourism; - Temperature up to -40; - Humidity up to 93%; | - There is no need to use additive technologies in this subspace.                                  |-------------------------------------------------------------------------------------------------------|
| Fishing territories                  | - Territories of fish resources and infrastructure for their industrial production; - Temperature up to -60; - Humidity up to 93%; - Additive technologies can be applied on board vessels operating in water areas. | - Material Extrusion – FDM; - Directed Melting Deposition – DMD, DLMD; - Sheet Lamination – LOM, UAM. | - Printing small items on ships; - Repair of deformed items on ships.                                |
| The Northern sea route               | - Water area adjacent to the water area of the Russian Federation; - Includes the shipping route, as well as establishments that serve it; - Temperature up to -60; - Humidity up to 93%; - Additive technologies can be applied on board ships and service establishments. | - Material Extrusion – FDM; - Directed Melting Deposition – DMD, DLMD; - Sheet Lamination – LOM, UAM. | - Printing small items; - Repair of deformed items.                                                |
| Infrastructure for                   | - Military complexes and                                               | - Material Extrusion – FDM;                                                                          | - Construction of temporary                                                                         |
the protection of safe existence
- Temperature up to -60;
- Humidity up to 93%;
- It is possible to create acceptable humidity, temperature and static conditions for the 3D printer in the subspace.

- Directed Melting Deposition – DMD, DLMD;
- Stereolithography – SLA, DLP, DLS, CLIP, LCD;
- Sheet Lamination – LOM, UAM;
- Powder Bed Fusion – SIBM, SLM, SLS, DMLS, EBM, PBF.

facilities;
- Printing small items;
- Repair of deformed items;
- Prototyping, building layouts and test samples.

5. Discussion
The analysis of possibilities of modern additive technologies for the accepted classification of the Arctic subspaces of the Russian Federation has shown encouraging results.

Additive technologies in the Arctic region of the Russian Federation can preferably be used for small-scale printing of items, repairs, prototyping and building layouts. The main advantages of using the technology are reduced production time, the ability to optimize them and reduce production costs for small-scale printing. The main limitations for using 3D printers are severe weather conditions, distortion when printing on mobile objects, the need to have a relatively large size of some printers and their high cost.

6. Conclusion
The introduction of modern scientific, technical and technological developments in various branches of the industrial sector of the Russian economy is a necessary condition for maintaining the state’s competitiveness in the world market.

Additive technologies are a young technological direction that can increase the efficiency of using labor, material, financial and other resources, which can lead to intensive economic growth. However, boundaries of these technologies use have not yet been established.

Expanding boundaries of additive technologies use will increase economic effect of their application by scaling this technology to new industries and regions. In this regard, the Arctic region is one of the areas of potential application of additive technologies.

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