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SUBSTANTIATION OF THE OPTIMAL LOCATION OF GOODS PRODUCTION USING 3D PRINTING TECHNOLOGIES: A SYSTEM APPROACH

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Purpose: The main purpose of the article is to identify the factors of optimal location of the production of benefits using 3D printing technologies and to develop criteria for identifying within the space of possible placement of potential locations for the production of benefits using 3D printing technologies. This will make it possible to justify the optimal location of the production of benefits using 3D printing technologies based on a system approach.
Design/methodology/approach: The correct justification of the optimal location of 3D printing production is possible only based on a system approach that involves considering the competition of other (interchangeable) technologies, as well as the simultaneous justification of production capacity and supply volumes to specific sales markets.
Findings: The location factors for producing goods using 3D printing technologies are relatively low prices for electricity and 3D printing materials, as well as a short distance to the sales markets and a developed transport infrastructure between the potential places of production 3D printing and potential sales markets. All locations from the space of possible placement that are characterized by at least one placement factor can be considered attractive locations for the production of benefits using 3D printing technologies, but the locations with the key placement factors for the production of benefits using 3D printing technologies - a short distance to sales markets - are of particular importance.
Practical implications: Use of the materials of the research conducted in the article can be of significant practical importance, since the correct substantiation of the optimal location of production using 3D printing technologies will allow to fully utilize the potential efficiency of these perspective technologies, which are promising in terms of increasing the economic security of individual firms, countries and the European Union as a whole.
Originality/value: The article identifies the factors of the production location using 3D printing technologies, develops a categorization of attractive places for the production location using 3D printing technologies, and proposes a methodology for determining the pointwise, locally and systemically optimal production technologies.
Keywords: system approach; 3D printing technologies; optimal production location; places of potential production location; factors of production location.
Category of the paper: Research paper.

1. Introduction

3D printing is one of the most promising production technologies, the importance of which is constantly growing in various sectors of the economy and this trend is increasing every year (Praveena et al., 2022; Jadhav et al., 2022; Ronchini et al., 2023; Stentoft et al., 2023; Jandyal et al., 2022). Like every promising production technology, 3D printing should be researched in terms of the location factors, since only the optimal production location will allow the full utilization of the potential efficiency of the respective technology. Not an optimal location reduces the potential efficiency of the production technology, which in some cases may make it inappropriate to use it. Obviously, such a situation would lead to significant losses and erroneous conclusions about the efficiency of the technology. Therefore, the issue of substantiation of the optimal location of 3D printing production is important and relevant.

Although 3D printing technology has generated considerable media hype, it has long been ignored in academic circles (with the exception of industry journals focused on technology research). Only in 2015, a scientific article was published that emphasized that 3D printing technologies have the potential to transform the global location of production (Gress, Kalafsky, 2015). Publications that explore the issues of the production location of 3D printing emphasize a clear trend toward the optimal location of 3D printing production in sales markets (Strange, Zucchella, 2017; Costabile et al., 2017; Sasson, Johnson, 2016; Rehnberg, Ponte, 2018; Haefner, Sternberg, 2020; Fraske, 2022). Some researchers are convinced that this trend will lead not only to the return of production from China and other countries with relatively cheap labour to North America and Western Europe (where the massive relocation of the industry once took place) but also to the general decentralization of production in the world (Ben-Ner, Siemsen, 2017). This prediction is based on the fact that the production using 3D printing technologies is characterised by relatively minor spatial differentiation of the costs of production (therefore, locating in a place with minimal costs will not provide significant savings), and locating near sales markets will save on the costs associated with moving goods from the place of production to sales markets.

Other scientists, while agreeing with the forecasts of the global economy reformatting from powerful production facilities in regions with cheap labour to a lot of small production facilities close to sales markets, emphasize that, in addition to logistical advantages (since materials for the production are easier and cheaper to transport than finished goods), the focus at the location on sales markets will allow better satisfaction of customer needs through direct cooperation to respond more quickly to changes in demand and reduce order processing time (Tang, Veelenturf, 2019).

In the same mean, researchers believe that 3D printing has the potential to revolutionize the process of producing and delivering goods to customers by enabling the transition from centralized to decentralized supply chains and reducing the costs associated with transportation and warehousing (Tang, Veelenturf, 2019). An important factor that will help bring the location of the production using 3D printing technologies closer to sales markets is the factor related to the environmental friendliness of these technologies: compared to the traditional technologies, they reduce contaminants many times over (Bogers et al., 2016). This is an important point, as industries with significant contaminants amount tend to be located in places (countries and regions) with low requirements for environmental protection. The environmental friendliness of 3D printing technologies is changing this situation. Therefore, it is actually generally accepted in the scientific community that long global supply chains will be replaced by cheap production using 3D printing technologies in almost every sales market (Culot et al., 2020; Ancarani, Di Mauro, 2018; Halassi et al., 2019; Gong et al., 2022; Theyel et al., 2018; Busch et al., 2021; Pour et al., 2016).

2. Steps of substantiation of the optimal location of the production

However, this is too general a thesis, since only by solving the problem of the optimal location of the production facilities and their optimal capacity can we get the right answer about the "binding" of production facilities to "their" sales markets. In this case, it is necessary to estimate the size of the sales market: there are many options, from the minimum size (production at the place of consumption, for example, in an apartment) to the maximum size (production for the market of a territorial unit, for example, a city). It can be predicted that some goods will have to be produced at the place of consumption (residence), but for economic reasons (small-scale production is not profitable) and due to safety conditions (noise, environmental contaminants during 3D printing), production will be carried out in the special facilities and in the amount that will provide for the most efficient use of the capacity of the relevant equipment (3D printer).

In order to set the step for the research of the optimal location of the production using 3D printing technologies, we briefly outline our approach to substantiation of the optimal location of goods production (Table 1). Since the components of the sequence of actions shown in Table 1 have been described in detail in previous publications (Stadnicki, Terebukh, 2022; Stadnicki, Bashynska, 2023), in this article we will focus on the positioning of 3D printing in some of the steps of substantiation of the optimal location of the production. Let's start with the space of possible locations. Although 3D printing technologies, regardless of the goods to be produced, are oriented towards sales markets and the space of possible locations of 3D printing production would be relatively minor (it could even be limited to the space of the relevant sales markets), competition with other technologies necessitates a significant expansion of the space of possible locations - to the level of national or even global. But for 3D printing technologies, the task will be made easier by the fact that even within the expanded space of possible locations, attractive places for production will be only near sales markets.

Table 1.
Steps of substantiation of the optimal location of the production

Step	Content of the step
1.	Determine what we plan to produce (declaration of intent)
2.	Outline the space for the possible location of the production
3.	Identify potential sales markets and estimate the demand for each of them
4.	From the potential sales markets, form variants of sales markets and calculate the demand for each of them
5.	Form a list of technologies of the production
6.	Identify the factors of the production location
7.	Within the places of a possible production location, identify places that are attractive for the production location
8.	For each place that is attractive for the production location, substantiate the pointwise optimal production technologies, while orienting the location to the appropriate sales market options
9.	Form a list of technologies of transportation between each attractive place for the production and all potential sales markets for the appropriate sales market option
10.	Substantiate the optimal transportation technologies between each attractive place for the production and all potential sales markets for the appropriate sales market option
11.	For each market option from the set of its attractive place for the production, determine the locally optimal place of the production and locally optimal production technologies and transportation
12.	From the locally optimal places of all sales market options, form options for potential systemically optimal places with potentially systemically optimal production technologies and transportation
13.	From the options of the potential systemically optimal places, substantiate the choice of the best one, i.e., the option of systemically optimal places with systemically optimal production technologies and transportation
14.	Evaluate the feasibility of implementing the optimal investment option, i.e. the option of systemically optimal places with systemically optimal production technologies and transportation

Source: Author’s development.

Potential sales markets should be identified by taking into account the space of possible locations, which will allow identifying places that will require customs payments when exporting goods produced there, or places on the territory of states that are under various sanctions. Taking into account the transportability of the goods to be produced, it is advisable to aggregate the demand of potential sales markets: with increasing transportability, the space for aggregating demand increases. However, it should be emphasized that aggregation of demand from potential sales markets should be done with caution. It is better to "under-aggregate" than to "over-aggregate". "Under-aggregation" may necessitate additional time and money spent on data collection and processing, but it will guarantee a high-quality result in terms of the optimal location of the production. "Over-aggregation" will save some time and money in data collection and processing, but may lead to mistakes in the optimal location of the production, mistakes that can have very large financial consequences.

Focusing 3D printing production which are close to sales markets can reduce the number of potential sales markets (by ignoring sales markets that are far from the potential places of the production using 3D printing technologies), but again, there are certain risks. For example, ignoring distant sales markets will save time and costs for collecting and processing some data (e.g., data for determining the distance and data to substantiate the choice of the optimal transportation technology from the places of a potential production using 3D printing technologies to the relevant sales markets for different types of transport), but it may lead to the possibility of accidentally ignoring effective potential sales markets with the corresponding consequences for the quality of decisions on production location.

Sales market options are formed and characterized by the potential sales markets that are part of these sales market options (obviously, some potential sales markets can be part of several sales market options). It is the sales market options that will act as "demand units", the orientation to which, when locating production, will determine the potential production capacity (and, accordingly, unit and total production costs), as well as the directions and volume of transportation (and, accordingly, unit and total transportation costs). Restricting the orientation in substantiation of the optimal location of production to only one particular option of the sales market (regardless of whether it is formed from one or more potential sales markets) would be erroneous (the only exception is when, for some reason, there is only one sales market - in this case, the orientation to it alone is permissible in substantiation the optimal location of the production), since it is not system and does not take into account competitive options.

If the orientation of the production using 3D printing technologies to nearby sales markets reduces the number of potential sales markets, then the number of sales market options will automatically decrease, but again, there are certain risks. Yes, this will save time and money on collection and processing data (for example, calculating production costs for some capacity options and transportation costs to some potential sales markets), but it is a threat with the possibility of accidentally ignoring effective sales market options with the corresponding consequences for the quality of final decisions on the production location.

Regarding the formation of a list of the production technologies. This list, along with 3D printing technologies, will include other technologies for the production of the valued goods, since, as a rule, any goods can be produced using several interchangeable technologies. The technologies on this list are competing and interchangeable, although some of them will be mutually supportive (when the optimal system of places of the production location is characterized by an optimal set of technologies that are mutually supportive in this system since it is the sets of technologies that compete with each other).

3. Location factors for production using 3D printing technologies

Regarding the identification of the production location factors. It is obvious that the strength of the influence of the factors of the production location is proportional to its impact on the criterion of optimal production location, which is the minimum total cost of the production of the required volume of goods and the cost of their movement (including transportation and warehousing costs, as well as, if necessary, customs payments) from the places of the production to the consumers (sales markets) in the amount of their demand. Since production costs are primarily the costs of resources required, the spatial differentiation of the resource prices, the need for resources, and the quality of resources leads to spatial differentiation of the production costs.

Production using 3D printing technologies is driven by demand:

1) 3D printers,
2) electricity,
3) materials for 3D printing,
4) software,
5) employees for 3D printing maintenance,
6) the space required to organize the production.

The main factor in the spatial differentiation of the production costs using 3D printing technologies will be the spatial differentiation of costs for electricity and 3D printing materials since the situation with other resources will be as follows: in different places, the prices of 3D printers and software will not differ significantly, and the price of work related to the direct operation of the 3D printer will have a small impact on the overall production costs. It follows that places (relevant cities, regions, countries) with relatively low prices for electricity and materials for 3D printing will be attractive for the location of the production using 3D printing technologies.

Table 2 shows the results of the analysis to identify which resources for the production of goods using 3D printing technologies can be factors in the location of such production, and the availability and relatively low price of its resources.

Table 2.
Results of the analysis of resources for 3D printing

Resources for 3D printing	Share in production costs	Spatial price differentiation	Is location a factor?
3D printers	Significant	Small	No
Electricity	Significant	Small locally; Significant globally	Yes
Materials for 3D printing	Significant	Medium	Yes
Software	Medium	Small	No
Employees for 3D printing maintenance	Small	Significant	No
Space required to organize production	Small	Significant	No

Source: Author’s development.

The results of the analysis show that the location factors for producing goods using 3D printing technologies are the relatively low prices of electricity and materials for 3D printing. However, the location factors for producing goods using 3D printing technologies are not only at the step of the production but also at the step of the transportation of goods from the place of production to the sales markets.

The advantage of low prices for electricity and materials for 3D printing can lose value by the high costs of the transportation of goods produced in a place with low prices for these resources to sales markets, compared to the costs of the transportation of goods to an alternative production place near sales markets. The possibility of such a situation (losing value) is due to the fact that, first, finished goods are usually not adapted to the transportation process, so they are subjected to actions aimed at increasing their transportability, which is associated with costs. Secondly, the transportation of goods produced in a place with low prices for electricity and 3D printing materials may involve the need for import customs payments if the relevant place is outside the common customs area (import customs payments for finished goods are usually much higher than import customs payments for resources). For the above reasons, the transportation of resources for 3D printing will require lower costs than the transportation of finished goods. Therefore, the proximity of the place to sales markets is a location factor for producing using 3D printing technologies. Although, obviously, the tendency to approach sales markets will be largely determined by the type of goods, since the ratio of how much cheaper it will be to transport materials than finished goods will strongly depend on the type of goods.

Access to good transportation infrastructure to a certain extent loses value the distance from sales markets. Therefore, a well-developed transportation infrastructure between places of potential production using 3D printing technologies and potential sales markets, which reduces logistics costs, is also a location factor for producing using 3D printing technologies.

According to the results of the analysis, Table 3 shows the location factors for producing using 3D printing technologies.

Table 3.
Location factors for producing using 3D printing technologies

No. of the factor	Name of the factor
1	Relatively low price of electricity
2	Relatively low prices of materials
3	Access to infrastructure
4	Proximity to sales markets

Source: Author’s development.

4. Attractive places for the production location using 3D printing technologies

Identification of attractive places for the production within a potential location space. Not every attractive place for the production within a potential location space needs to be considered as an attractive production location for every sales market option. Some attractive places for the production within a potential location space may not be suitable in terms of production volume (taking into account environmental restrictions, and the amount of resources needed) for the location of a large-scale production, i.e., one that is oriented to a market option with significant demand. It is clear that orientation to sales market with high demand, which means high production capacity, will lead to a significantly smaller number of attractive places for the production than orientation to sales market with low demand since low production requires fewer different resources and is less affected by environmental restrictions.

In general, all locations in the space of possible locations that are characterized by at least one of the 4 factors identified (relatively low electricity prices, relatively low material prices, access to good transportation infrastructure, proximity to sales markets) can be considered attractive places for the production of goods using 3D printing technologies (Table 4).

Table 4.
Categories of attractive places for the production using 3D printing technologies

Category of places	Factors			
	1-comparatively low price of electricity	2-comparatively low prices of materials	3-access to infrastructure	4-proximity to sales markets
1-1	+	-	-	-
1-2	-	+	-	-
1-3	-	-	+	-
1-4	-	-	-	+
2-(1+2)	+	+	-	-
2-(1+3)	+	-	+	-
2-(1+4)	+	-	-	+
2-(2+3)	-	+	+	-
2-(2+4)	-	+	-	+
2-(3+4)	-	-	+	+
3-(1+2+3)	+	+	+	-
3-(1+2+4)	+	+	-	+
3-(1+3+4)	+	-	+	+
3-(2+3+4)	-	+	+	+
4-(1+2+3+4)	+	+	+	+

Source: Author's development.

In this table, the category of place depends primarily on the number of factors (location of the production using 3D printing technologies) that are presented in the respective place. That is, places with only one factor are encoded at the beginning with the digit "1" (1-1, 1-2, 1-3, 1-4); places with two factors are encoded at the beginning with the digit "2" (2-(1+2), 2-(1+3), 2-(1+4), 2-(2+3), 2-(2+4), 2-(3+4)); places where three factors are present are encoded at the beginning with the digit "3" (3-(1+2+3), 3-(1+2+4), 3-(1+3+4), 3-(2+3+4)); places where all four factors are present are encoded at the beginning with the digit "4" (4-(1+2+3+4)). The second component of the place categorization code characterises which factors are present in the respective places.

Attractive places for the production in category 1 will be the least likely to be selected for the location of goods production using 3D printing technologies, as they will be characterized by the presence of only one location factor (4 subgroups: 1-1, 1-2, 1-3, 1-4). However, it should be emphasized that a special subgroup will be formed by places in categories 1-4, since proximity to sales markets should still be considered a key factor of the location of goods production using 3D printing technologies.

For attractive places for the production of category 2, the probability of being selected for the location of goods production using 3D printing technologies will increase, as it will be characterized by the presence of two location factors (6 subgroups: 2-(1+2), 2-(1+3), 2-(1+4), 2-(2+3), 2-(2+4), 2-(3+4)). The special subgroups among places of category 2 will be 2-(1+4), 2-(2+4), and 2-(3+4), due to the presence of a key factor of the location of goods production using 3D printing technologies - proximity to sales markets.

Attractive places for the production in category 3 will be even more likely to be selected for the location of the production using 3D printing technologies, as it will be characterized by the presence of as many as three location factors (4 subgroups: 3-(1+2+3), 3-(1+2+4), 3-(1+3+4), 3-(2+3+4)). The special subgroups among the locations of category 3 will be 3-(1+2+4), 3-(1+3+4), and 3-(2+3+4), due to the presence of a key factor of the location of goods production using 3D printing technologies, namely, proximity to sales markets.

Obviously, the most likely to be selected for the production location using 3D printing technologies will be attractive places for the production of category 4 (1 subgroup: 4-(1+2+3+4)), as they will be characterized by the presence of all four location factors. However, it should be expected that there may be few places in category 4 (and the situation of its absence is quite possible) places of category 4, so to improve the quality of the analysis, it is advisable to research attractive places of production locations of category 3 (all subgroups), as well as individual subgroups of category 2 (2-(1+4), 2-(2+4) and 2-(3+4)) and even one subgroup of category 1 (1-4).

5. Pointwise, locally and systemically optimal production technologies

Regarding the substantiation of the optimal technologies. Technology competition should be considered in relation to attractive places of production locations and sales market options. Technologies that will be evaluated for particular attractive places of production locations for the relevant sales market option will compete with each other. Technologies that win in the competition of technologies in a particular attractive place (in terms of minimum production costs in the amount of demand of the relevant sales market option) are identified as point-optimal technologies for the relevant attractive places: each attractive place of production locations of each sales market option will have its own point-optimal technology (the number of point-optimal technologies in each attractive place is equal to the number of sales market options that this location will be targeted at).

The following three situations can be found in specific attractive places with regard to point-optimal technologies (which may apply to a single sales market option or to all sales market options):

1P) All point-optimal technologies are 3D printing technologies;

2P) Some of the point-optimal technologies are 3D printing technologies;

3P) All point-optimal technologies are not 3D printing technologies.

Point-optimal technologies in specific attractive places of each sales market option will compete with each other at a distance, creating local spatial competition of technologies. The technology that wins this competition (in terms of the minimum total production costs in the amount of demand of the respective sales market option and transportation costs to potential sales markets of the respective sales market option in the amount of demand of these potential sales markets) of point-optimal technologies in specific attractive places of the sales market option becomes the locally optimal technology. Each sales market option will have its own locally optimal technology (the number of locally optimal technologies is equal to the number of sales market options). The following three situations can occur with respect to locally optimal technologies (which apply only to all sales market options):

1L) All locally optimal technologies are 3D printing technologies;

2L) Some of the locally optimal technologies are 3D printing technologies;

3L) All locally optimal technologies are not 3D printing technologies.

Obviously, the situations of locally optimal technologies depend on the situations of point-optimal technologies in specific attractive places. For example, if a 1P situation is created for all sales market options (all point-optimal technologies in specific attractive places are 3D printing technologies), then a 1L situation (all locally optimal technologies are 3D printing technologies) is inevitable. If, on the other hand, a 3P situation is created for all sales market options (all locally optimal technologies are not 3D printing technologies), then a 3L situation (all locally optimal technologies in specific attractive places are not 3D printing technologies) is inevitable. If a 2P situation is created for all sales market options (some of the point-optimal technologies in attractive places are 3D printing technologies), then each of the above situations is possible for locally optimal technologies: situation 1L (all locally optimal technologies are 3D printing technologies), situation 2L (some locally optimal technologies are 3D printing technologies), and situation 3L (all locally optimal technologies are not 3D printing technologies). The described dependence between the optimal technologies of the "P" and "L" levels is well characterized in Table 5.

Locally optimal technologies of sales market options not only compete but also mutually support each other since its competition takes place as part of options of potential systemically optimal technologies (the set of locally optimal productions, the total capacity of its is equal to systemic demand, forms an option of potential systemically optimal productions). At the same time, a situation may arise when the locally optimal 3D printing technology of a particular sales market option competes not only with other interchangeable locally optimal technologies of other sales market options but also with other locally optimal 3D printing technologies of other sales market options. To some extent, it is paradoxical that a locally optimal technology (that could be a 3D printing technology) can compete with itself, since it may be present in different competing technology systems.

Table 5.
Dependence between optimal technologies of "P" and "L" levels

If at the "P" level	Then at the level of "L" are inevitable (+ or "-") or possible (±)		
	1L) All locally optimal technologies are 3D printing technologies	2L) Some of the locally optimal technologies are 3D printing technologies	3L) All locally optimal technologies are not 3D printing technologies
1P) All point-optimal technologies are 3D printing technologies	+	-	-
2P) Some of the point-optimal technologies are 3D printing technologies	±	±	±
3P) All point-optimal technologies are not 3D printing technologies	-	-	+

Source: Author's development.

Competition of sets of locally optimal technologies of sales market options (options of potential systemically optimal technologies) means systemic spatial competition of technologies. At the same time, in each set of locally optimal technologies of the options of sales markets, technologies are actually mutually supported, since together they constitute a single entity - a system of technologies competing with other systems of technologies. In the case of mutual support of technologies within the options of potential systemically optimal technologies, a situation may arise when the locally optimal 3D printing technology of a sales market option is mutually supported not only with other locally optimal 3D printing technologies of other sales market options but also with other locally optimal technologies (which are not 3D printing technologies) of other sales market options.

Obviously, the situations of systemically optimal technologies depend on the situations of locally optimal technologies. Thus, if a 1L situation is created for all sales market options (all locally optimal technologies are 3D printing technologies), then situation 1S (all systemically optimal technologies are 3D printing technologies) is inevitable. If a 3L situation is created for all sales market options (all locally optimal technologies are not 3D printing technologies), then the situation 3S (all systemically optimal technologies are not 3D printing technologies) is inevitable. If a 2L situation is created for all sales market options (some locally optimal technologies are 3D printing technologies), then each of the following situations is possible for systemically optimal technologies: situation 1S (all systemically optimal technologies are 3D printing technologies), situation 2S (some systemically optimal technologies are 3D printing technologies), and situation 3S (all systemically optimal technologies are not 3D printing technologies). The described dependence between the optimal technologies of the "L" and "S" levels is well characterized by Table 6.

Table 6.
Dependence between optimal technologies of "L" and "S" levels

If at the "L" level	Then at the "S" level are inevitable (+ or "-") or possible (±)		
	1S) All systemically optimal technologies are 3D printing technologies	2S) Some of the systemically optimal technologies are 3D printing technologies	3S) All systemically optimal technologies are not 3D printing technologies
1L) All locally optimal technologies are 3D printing technologies	+	-	-
2L) Some of the locally optimal technologies are 3D printing technologies	±	±	±
3L) All locally optimal technologies are not 3D printing technologies	-	-	+

Source: Author’s development.

6. Conclusions

Let us focus on the main points of the article.

1) 3D printing is one of the most promising production technologies, but only optimal location will allow to fully utilize the potential efficiency of this technology;
2) Although 3D printing technologies, regardless of the goods to be produced, are oriented towards sales markets and its individual space of possible locations would be limited, competition with other technologies necessitates a significant expansion of the space of possible locations;
3) When forming the list of production technologies, along with 3D printing technologies, there will be other production technologies of the valued goods (interchangeable, which under certain conditions can become mutually supportive);
4) The location factors for producing goods using 3D printing technologies are the relatively low prices of 3D printing materials and electricity, as well as access to good transportation infrastructure and proximity to sales markets;
5) The most likely to be selected for the location of production using 3D printing technologies will have attractive places for production with all four location factors. However, in order to improve the quality of the analysis, it is advisable to research attractive places of production locations that have fewer factors of production location: first of all, with the presence of the factor "proximity to sales markets";
6) For each place that is attractive for production location, the criterion of minimum production costs for a given capacity (equal to the demand of the relevant sales market option) is used to substantiate the point-optimal production technology (pointwise competition of technologies). Subsequently, it is the spatial competition of point-

optimal technologies (in terms of the minimum total costs of production and movement of goods) that will allow the identification of locally optimal places of production and locally optimal technologies for each sales market option;

7) The option of a set of locally optimal places with the lowest total costs (for production and movement of goods to consumers) will be optimal, and the locally optimal places of this option are identified as systemically optimal places where necessary to locate production with appropriate technologies, production with appropriate technologies, which are identified as systemically optimal technologies, and with appropriate capacities, which are identified as the systemically optimal capacities.

Thus, the correct substantiation of the optimal location of the production using 3D printing technologies is possible only based on a systematic approach that takes into account the competition of other (interchangeable) technologies, as well as the simultaneous substantiation of production capacity and supply volumes to specific sales markets. In the future, research in this area should focus on the problem of the range of production, which means that it is necessary to expand the research of the complexity of production in the direction of a "set of goods" that should be produced in appropriate places using appropriate technologies, in appropriate volumes and for appropriate sales markets. The problem of transforming interchangeable competing technologies into mutually supportive technologies deserves thorough scientific research. Another promising area of research in this area is to assess the impact of 3D printing technologies on the spatial organization of the economy as a whole. One of the results of changes in the spatial organization of the economy under the influence of 3D printing technologies will be a decrease in the role and volume of international trade, which should also be the subject of scientific research.

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