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## Organizational and economic impact of implementation additive technologies in construction

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The use of additive technologies in combination with other technologies that provide the transition from model to the finished product is actively used in the industry of many countries. The use of such technologies in combination with casting one allows you to make certain types of sculptures. Modeling of sculptures in specialized software packages without the participation of a sculptor is still not possible, so the most promising direction for town planning is the production of relatively simple in shape models of prominent historical and cultural buildings and entire cities. The ability to 3d print the developed model greatly simplifies and speeds up the production of a master model for further metal casting. The conducted cost analysis showed savings of 15-17% in the transition from manual production of a master model by a sculptor to modeling and 3d printing.

**Keywords:** additive technologies, economic efficiency, casting, master model, sculpture

## Організаційно-економічний вплив впровадження адитивних технологій в будівництві

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Застосування адитивних технологій в комплексі з іншими технологіями, що забезпечують перехід від макетування до готового виробу активно використовуються в промисловості багатьох країн. Застосування таких технологій в комплексі з ливарними дозволяє виготовляти окремі види скульптур. Моделювання скульптур в спеціалізованих програмних пакетах без участі скульптора все ще не можливе, тому найперспективнішим напрямом для містобудування є виготовлення, відносно простих за формою, макетів визначних історико-культурних будівель та цілих міст. Можливість 3d друку розробленого макету значно спрощує та прискорює виготовлення майстер-макету для подальшого лиття металом. Роздільно здатність 3d принтерів в десятки мікрон дозволяє друкувати елементи майстер-макету з величезною деталізацією, а сучасні технології лиття забезпечують якість кінцевого виробу. Тобто основною перевагою від впровадження адитивних технологій в процес розробки та виготовлення макетів історичних будівель та споруд є мінімальне використання часу скульптора, відмова від роботи з скульптурними матеріалами на користь комп'ютерного моделювання та швидкий друк з значною деталізацією. Однак заміна роботи професійного скульптора на роботу спеціаліста з комп'ютерного моделювання значно звужує область застосування технології. Фактично раціональним є виготовлення копій старовинної забудови міст та окремих замків, церков, будинків. Розглянуті в роботі макети дозволяють припускати стрімкий розвиток такої технології в найближчому часі, а зважаючи на туристичний потенціал міст України технологія буде мати практичне застосування принаймні з два десятки років. Проведений аналіз витрат на прикладі бронзового макету «Чернігівська фортеця початку XVIII ст.» показав економію коштів в 15-17% при переході з ручного виготовлення майстер-макету скульптором на моделювання та 3d друк.

**Ключові слова:** адитивні технології, економічна ефективність, лиття, майстер-макет, скульптура



## Introduction

The advantages of the introduction of additive technologies in the development and manufacture of various models are undoubted, but the use of these technologies in combination with others, such as casting, to obtain a finished architectural product requires more experience and active discussion.

The development of master models for casting requires a lot of time and manual labor of the sculptor and the architect, but if there are repetitive or similar objects in the project, it is possible to apply a computer simulation with subsequent 3D printing. This approach significantly reduces the production time of the master model, and the high resolution of modern 3D printers increases their detailing.

## Review of research sources and publications

One of the modern trends in construction is to support the concept of inclusive urban space. As part of this concept, bronze models of historic buildings [1, 2] or individual historically important buildings have appeared in many cities with a rich historical past [3] (Fig. 1).

A distinguishing feature of such models with high digitalization and duplication of inscriptions in Braille is their tactility. It is especially important for children and persons with visual deficiency.

## Definition of unsolved aspects of the problem

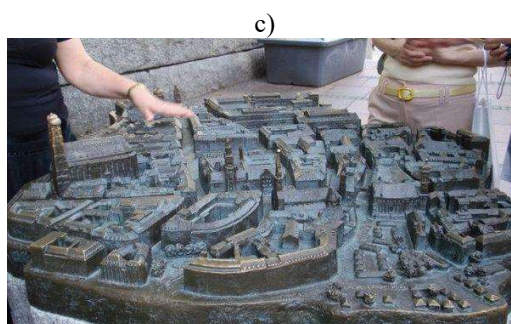
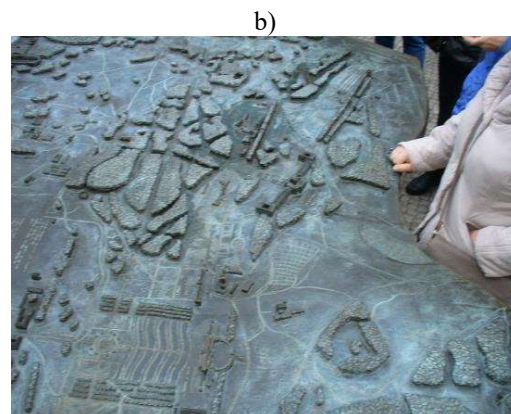
The question of expediency and limits of using 3D printing in architectural and town planning projects is still insufficiently covered. In the first place, there is the possibility of replacing the sculptor's manual with repetitive and simple in shape objects, but with a large number of small details.

## Problem statement

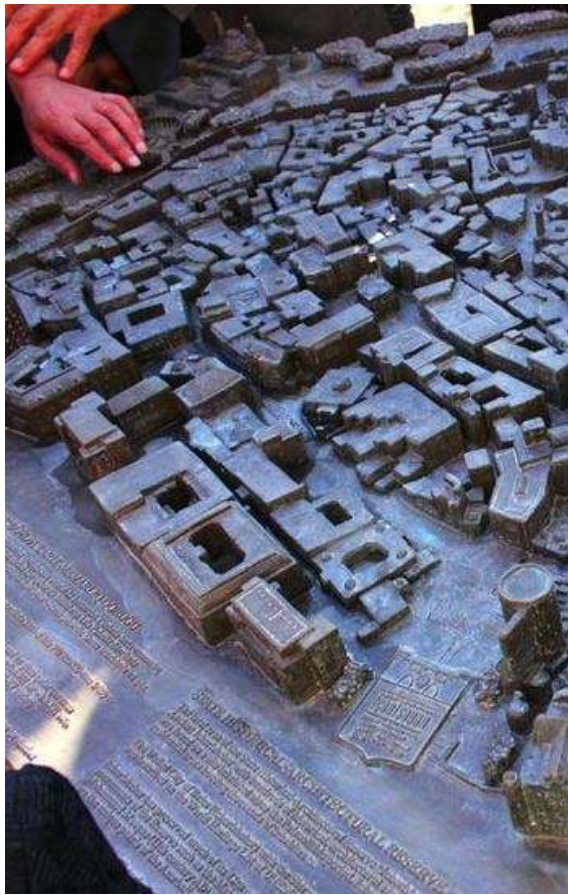
To determine the limits of the use of 3D printing in the manufacture of a master model for casting on the example of a bronze model "Chernihiv Fortress of the early XVIII century".

## Basic material and results

Development of projects in architecture and town planning is always a complex and multi-vector process that requires visualization of decisions [4]. The current level of CAD systems allows to realistically model urban development and landscape at the design stage of the construction object, and the availability of additive manufacturing technologies (Additive Manufacturing, AM) speeds up and reduces the cost of the model [5, 6]. In most projects, the use of AM-technologies is limited to this [7], but for projects with sculptural compositions, it becomes possible to make a master model for casting. The reorientation of AM from the field of visualization and presentation models to the final product is a global trend. So, the percentage of AM-technologies in the manufacture of master models for metal casting in 2004 was 8.1%, and in 2013 – 10.8% [7]. One of the successful examples of the additive technologies used is the tactile project of Cyril Rabat in Baku [8] (Fig. 2).



**Figure 1 – Examples of existing bronze models:**  
a – Church of St. Mary of the Perpetual Assistance, Ternopil (Ukraine) [2];  
b – Sanssouci Park (Germany) [1];  
c – Old part of Munich (Germany) [3]



**Figure 2 – Tactile model, Baku (Azerbaijan) [8]**

A model of the historic part of Baku was made in 2017 in co-authorship with German architect Egbert Broerken.

In Ukraine the opportunity to carry out work on the production of master models for casting by AM technology entirely appeared in 2019. The historical part of the city of Chernihiv was chosen as the object of visualization, modeling, and master model making. According to the plan, the model should combine the existing churches and cathedrals with the buildings that surrounded them at the beginning of the XVIII century, immersing the visitor in the history of the city. For this purpose, the model has been installed in the center of the entrance group to the park “Chernihiv Dytnets”, which allows visitors to simultaneously observe the preserved architectural monuments and their model (Fig. 3). The bronze model is located on a stone pedestal. In a circle, at the foot of the stone, there are also the historical coats of arms of Chernihiv and tables with historical dates.

The sculptural composition consists of two groups of sculptures located in a semicircle on both sides of the bronze model “Chernihiv Fortress of the early XVIII century”. One group of sculptures depicts Prince Mstislav and Nestor the Chronicler, another – Colonel Martin Nebab, who was a close associate of Hetman Khmelnytsky, and the founder of the Chernihiv publishing house Lazar Baranovich. The author of the sculptures is Kyiv sculptor Oleksiy Shevchenko.

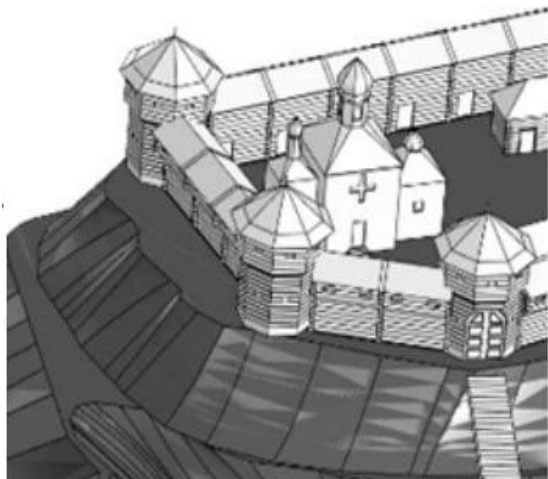
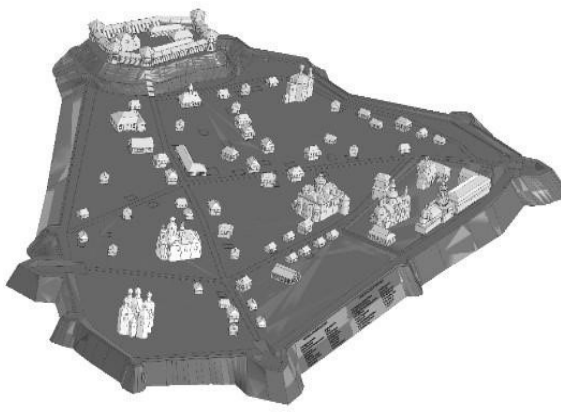
The author of the idea of the central part of the composition is the Chernihiv historian Oleksandr Bondar. The team of the Chernihiv Polytechnic National University was engaged in the introduction of AM-technologies in the project.

Modeling of elements was carried out according to the provided sketches. The presence of a digital model has greatly simplified and accelerated changes in the design of the model (Fig. 4). The significant advantage has been the presence in the model of three dozen buildings, represented by four repeating models, and the walls of the upper castle, formed by only three models. Changes in the placement of inscriptions and fonts also did not require the reworking of the master model. In addition, printing a series of identical elements significantly reduces printing time and the amount of waste.



**Figure 3 – Sculptural composition, Chernihiv (Ukraine), September 2020 [9, 10]**

The analysis of the economic efficiency of the project showed that the amount of cost savings for the production of a master model using 3D printing technology is 15-17% compared to the cost of manual labor of a professional sculptor. The production of master model elements was performed using FDM (Fused Deposition Modeling) technology, which according to ASTM F2792.1549323-1 (USA) belongs to the category of Material Extrusion technologies. FDM technology in this standard is described as a layered application of molten material using an extruder [11]. Additive technology laboratory printers, ZAVmaxPro models, were used for 3D printing. Glycol-modified polyethylene terephthalate (PETg) from 3DPlast was chosen as the printing material. The choice of material has been conditioned by its mechanical properties and low shrinkage during cooling. To reduce the printing time the height of the polymer layers was increased to 200  $\mu\text{m}$  and chemical smoothing of the finished surfaces was applied.



**Figure 4 – Intermediate variant of model design**

Each element of the master model was printed as separate parts (Fig. 5). The basis of the model together with the arrays of trees was made by milling MDF boards. The casting of the elements was performed on molten molds. Assembly of elements on the basis was performed by gas soldering.

Additionally, bronze plates with a description of the model elements were made by milling on CNC machines.

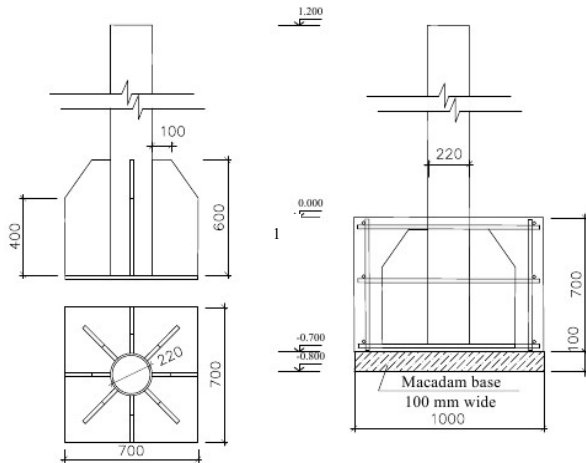


**Figure 5 – Printed elements of the master model before casting**

There are also certain requirements for the pedestals, on which the model must be placed.

The pedestals can be made in the form of a small pillar produced of brick, stone (mainly marble, granite), reinforced concrete, metal, or combined (for example, reinforced concrete lined with marble). Such pedestals usually do not require auxiliary requirements for the arrangement. The main condition is a secure attachment of the model and the base of the pedestal to the foundation. The depth of the foundation may be limited by town-planning conditions.

The authors propose to use a metal pipe with a diameter of 200-300 mm, which using metal plates has been reinforced to a reinforced concrete foundation with a depth of 0.7 m and by dimensions of 1 m per 1 m (Fig. 6). These dimensions allow you to keep the model from damage by vandals. The metal pipe can be painted, concreted, or faced with decorative materials (marble, granite).



**Figure 6 – Construction of the pedestal made of the metal pipe with a reinforced concrete foundation**

The decision to accept the massive elements can be dictated not only from architectural or design solutions but also from the point of view of anti-vandalism or at least for reasons of aesthetic appearance. It should be noted that the model has requirements not only for the safety of the environment (humans, animals, birds) but also requirements against vandalism.

When placing models in the city, special attention must be paid to the installation of a solid foundation for the objects. Although the model itself may be light, the pedestal on which the elements are placed can be large (several square meters) and usually made of marble, granite, or heavy concrete (the weight of such elements can reach several tons).

The weight of massive stones is usually distributed over the entire area of the pedestal, but if the estimation of the base reliability is incorrect, it can lead to excessive subsidence of the pedestal, especially in the presence of soils with special properties under the foundation base.

The stage of the concrete preparation of the pedestal and stages of installation of the pedestal and the ready model in Chernihiv are shown in Fig. 7, 8.



**Figure 7 – Concrete preparation under the pedestal for the model in Chernihiv [12]**



**Figure 8 – The stone with the bronze model of the Historic Dytynets in Chernihiv [13]**

In some cases, soil compaction or macadam or other concrete preparation under the base of the pedestal is not enough. In such cases, it is necessary to arrange artificial fixing of soil or replacement of weak soil on a more reliable basis.

The substantiation of rational decisions concerning the construction of a building on which the model is placed must be based on the complex analysis of the territory features taking into account the constructive decision of the object.

## Conclusions

The gradual introduction of AM technologies in complex and knowledge-intensive industries of developed countries is forcing our country to begin its research in various application fields of additive technologies.

One of the promising industries may be architecture and town planning. The most probable application for the given technology is the production of metal models of increased detailing and simplicity for modeling of forms.

The example of a bronze model “Chernihiv fortress of the early XVIII century” shows the possibility of accelerating the implementation of such projects through a complete transition to computer modeling and AM technology. Renunciation of the traditional process of the master model formation, in addition to saving time, also allows reducing the cost of the finished model by transferring from manual labor to an automated process and replacing the classic sculptural materials with polymer.

## References

1. *Парк Сан-Суси*. Взято з [https://www.tripadvisor.ru/LocationPhotoDirectLink-g187330-d501640-i148040065-Sanssouci\\_Park-Potsdam\\_Brandenburg.html](https://www.tripadvisor.ru/LocationPhotoDirectLink-g187330-d501640-i148040065-Sanssouci_Park-Potsdam_Brandenburg.html)
2. *Бронзовий Тернопіль*. Взято з <https://bronze.te.ua/>
3. *Бронзовый макет старой части города*. Взято з <http://www.openarium.ru/poi/28758556/>
4. Самойлов С.В. (2011). Освоение технологии производства художественного литья (изделий духовного назначения) из цветных металлов и сплавов. *Металл и литье Украины*, 9-10, 64-66
5. Ковалевский С.В., Гончарова Н.С. (2015). Развитие аддитивных технологий на основе послойного выращивания деталей машин. *Научный вестник Донбасской государственной машиностроительной академии*, 3, 149-154
6. Besklubova S., Skibniewski M.J. & Zhang X. (2021). Factors Affecting 3D Printing Technology Adaptation in Construction. *Journal of Construction Engineering and Management*, 147(5), 2034
7. *Характеристика рынка аддитивных технологий*. Взято з <https://extxe.com/9663/harakteristika-rynka-additivnyh-tehnologij>
8. *В Баку представлен уникальный проект – макет Ичеришехер в бронзе для слепых*. Взято з <https://news.day.az/society/907217.html>
9. *Ярослав Куц: скульптурна композиція на Валі – нова туристична принада Чернігова*. Взято з <http://svoboda.fm>
10. *Историко-скульптурная композиция на черниговском Валу готова!* Взято з <https://www.gorod.cn.ua>
11. *Классификация и терминология аддитивных технологий*. Взято з <https://extxe.com/9643/klassifikacija-i-terminologija-additivnyh-tehnologij/>
12. *На вході на Вал готують основу для встановлення макету Дитинця і скульптур*. Взято з <https://chernigiv-rada.gov.ua/news/id-43717/>
13. *При вході на Вал почали встановлювати скульптури і готувати місце під макет Дитинця*. Взято з <https://chernigiv-rada.gov.ua>
1. *Sanssouci park*. Retrieved from [https://www.tripadvisor.ru/LocationPhotoDirectLink-g187330-d501640-i148040065-Sanssouci\\_Park-Potsdam\\_Brandenburg.html](https://www.tripadvisor.ru/LocationPhotoDirectLink-g187330-d501640-i148040065-Sanssouci_Park-Potsdam_Brandenburg.html)
2. *Bronzed Ternopil*. Retrieved from <https://bronze.te.ua/>
3. *Bronze Model of the Old Town*. Retrieved from <http://www.openarium.ru/poi/28758556/>
4. Samoilov S.V. (2011). Mastering the technology for the production of artistic casting (spiritual products) from non-ferrous metals and alloys. *Metal and casting of Ukraine*, 9-10, 64-66
5. Ковалевский С.В., Гончарова Н.С. (2015). Development of additive technologies based on layered growing of machine elements. *Научный вестник Донбасской государственной машиностроительной академии*, 3, 149-154
6. Besklubova S., Skibniewski M.J. & Zhang X. (2021). Factors Affecting 3D Printing Technology Adaptation in Construction. *Journal of Construction Engineering and Management*, 147(5), 2034
7. *Description of additive technologies' market*. Retrieved from <https://extxe.com/9663/harakteristika-rynka-additivnyh-tehnologij>
8. *A unique project presented in Baku - model of Icherisheher in bronze for the blind*. Retrieved from <https://news.day.az/society/907217.html>
9. *Yaroslav Kuts: sculptural composition at the Val – new tourist allure of Chernihiv*. Retrieved from <http://svoboda.fm>
10. *Historical-sculptural composition on the Chernihiv Val is ready!* Retrieved from <https://www.gorod.cn.ua>
11. *Classification and terminology of additive technologies*. Retrieved from <https://extxe.com/9643/klassifikacija-i-terminologija-additivnyh-tehnologij/>
12. *At the entrance to the Val the basis for the installation of a model of the Baby and sculptures is preparing*. Retrieved from <https://chernigiv-rada.gov.ua/news/id-43717/>
13. *At the entrance to the Val the installation of sculptures and preparation a place for a model of the Dytynets has been begun*. Retrieved from <https://chernigiv-rada.gov.ua>