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EARTH-BASED MATERIALS FOR ADDITIVE MANUFACTURING IN CONSTRUCTION: A SELECTIVE REVIEW OF MIX DESIGN

ГРУНТОВІ МАТЕРІАЛИ ДЛЯ АДИТИВНОГО ВИРОБНИЦТВА В БУДІВНИЦТВІ:
ВИБІРКОВИЙ ОГЛЯД ПРОЕКТУВАННЯ СУМІШЕЙ

Maslyanenko Y.V./Масляненко Є.В.

PhD (Tech), as. prof./к.т.н., доц.

ORCHID: 0009-0009-2982-375X

Khlyitsov N.V./Хлицов М.В.

PhD (Tech), as. prof./к.т.н., доц.

ORCHID: 0000-0003-3713-6764

Odesa State Academy of Civil Engineering and Architecture,

Odesa, Didrikhsona, 4, 65029

Одеська державна академія будівництва та архітектури,

Одеса, Дідріхсона, 4, 65029

Abstract. A selective review of the up-to-date research on the additive manufacturing (AM) in construction - 3D printing technology from the earth-based materials perspective. Ways of tailoring effective mix design for the in-situ printing process using local materials.

Keywords: 3D printing; extrusion; mix design; printable earth-based structures.

Introduction.

Additive manufacturing (AM) of frame elements and buildings and structures in general has proven that it has the potential to become one of the most promising areas of development of the construction industry. AM offers a high level of process automation, higher quality of the final product due to the reduction of the impact of the human factor (mistakes) and a lower level of occupational hazard at the construction site compared to conventional construction process. At the same time, additive manufacturing is more adapted to modern design methods, such as front-load design with the great options of mass-customization.

Literature review. Originated from the traditional materials manufacturing and building techniques for the construction industry, the use of concrete with various types of binders and variety of aggregates and additives as a material for 3D printing has received wide attention and increased interest from researchers. An illustration of this interest can be the fact that over the decade the number of printed articles in SCOPUS related to research on improving the technology and formulation of C3DP formulations has increased almost 400 times [1].



Despite some success, concrete as a material for 3D printing have drawbacks that may affect its usage in the long run. First, it is a "carbon footprint" associated with both the energy-consuming production process and transportation costs – in many regions, cement or raw materials for cement clinker are imported materials. Cement-based building materials are quite difficult to recycle, and they have a very few options for reuse. Another factor that affects the widespread adoption of this technology is relatively high direct costs, both in terms of the cost of materials and equipment.

To reduce the negative impact on the environment and increase economic efficiency, the scientific approach is widely used. Scientists and researchers develop effective building mixtures using environmentally friendly materials [2], renewable biopolymers, by-products and industrial wastes, and processed products. Particular attention is paid to fillers – fibers of various origins and nano-materials that have a positive effect on rheological and mechanical properties [3, 4].

Unlike cement-based materials, soil mixtures are more compatible with modern environmental standards in terms of CO₂ emissions. Most local soil materials are suitable for the manufacture of mixtures for 3D printing with minimal processing (sieving). In addition, houses made of soil materials considered more effective for controlling temperature and humidity conditions inside the premises.

Review Aims and Scope.

The biggest disadvantages of soil mixtures for 3D printing is relatively high water content in the mixture and, accordingly, a longer drying time and gaining initial strength (green strength), a tendency to uneven deformations when drying and, as a result, the appearance of cracks. Soil mixtures have much lower strength characteristics compared to cement-based mixtures, as well as low resistance to moisture on finished structures. These shortcomings make it mandatory to use additives to improve the properties of the soil mixture.

Research Methodology.

The available reviews showed that use cements as additives decreases advantages of earth-based mixtures, although it allows increasing buildability (with the addition of ~15% of cement binder and, accordingly, reducing the amount of water to 22-28% of



the mass of dry components of the mixture) [5]. Therefore, the researchers' attention focused on the use of biodegradable and recycled polymeric and mineral materials as additives.

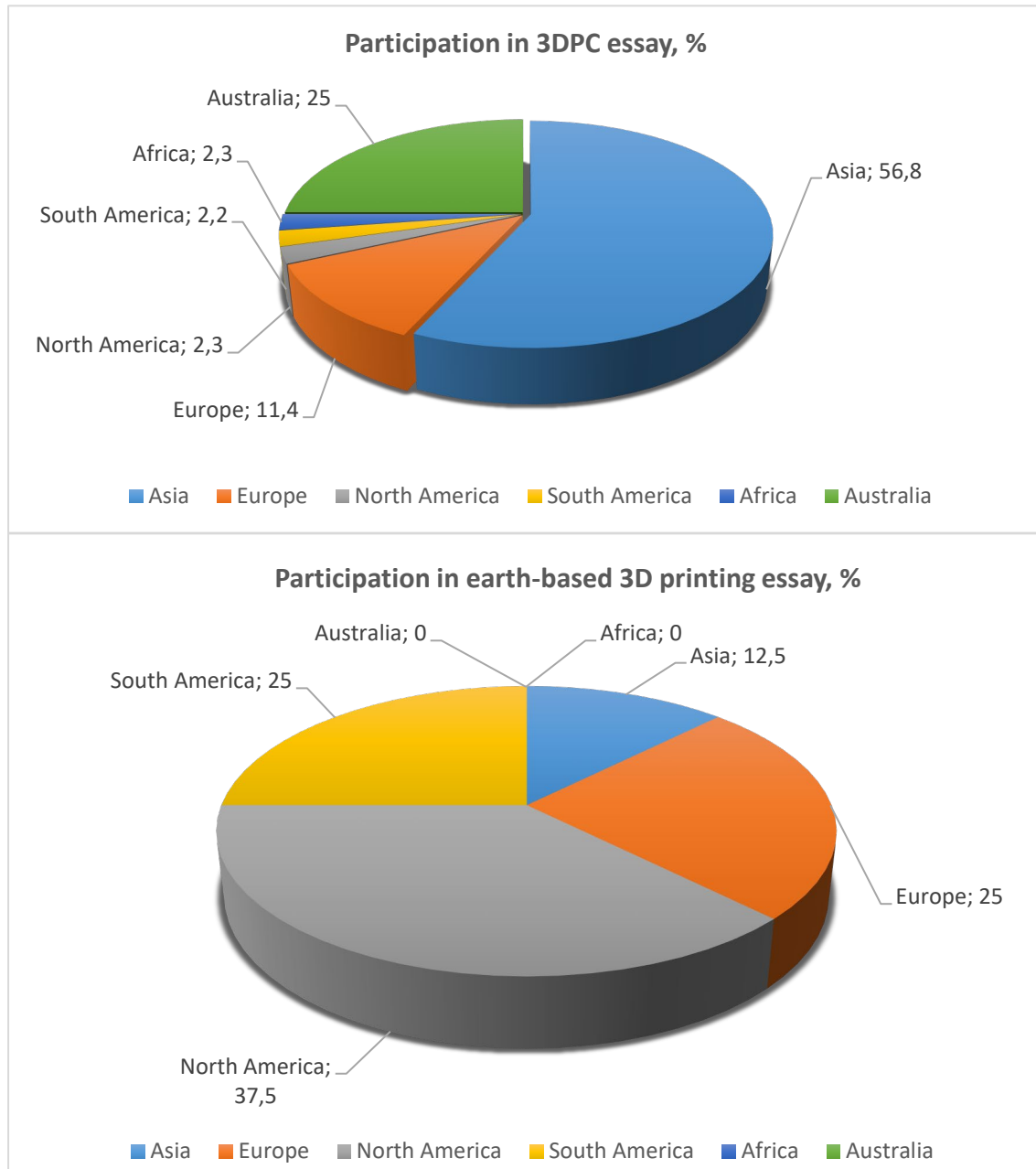


Figure 1

- a. *Participation of countries in 3DPC essay*
- b. *Participation of countries in earth-based 3D printing essay*

Research results.

An interesting illustration to the problem is the geographical distribution of studies of mixtures based on cement and soil materials (Figure. 1). Fast industrial



development in China, India and Middle East leads to use of concrete mixes as a preferable material for 3D printing. “Old’ world economics consider sustainability as a more suitable way of development and therefore, inclined towards soil-based matrices for additive manufacturing in construction.

Majority of researches of cement-based mixes concentrated on the study on the mixes’ technological properties by addition of various types of fibers (steel, polymer, etc.). The studies of soil mix designs examine the possibility of improving the characteristics of the mixture by adding organic by-products and industrial wastes.

To start with, it is necessary to mention pioneering study of the A. Perrot et al. Using of biopolymer – alginate (alginic salt Cimalgin HS3®) proved that it can considerably improve the time required to develop sufficient green strength of 3D printed earth wall, with final strength compatible to the rammed earth wall, but with no requirements for formwork [6].

The potential of use of local earthen materials in New Mexico, USA, were studied by the Department of Civil, Construction and Environmental Engineering University of New Mexico, Albuquerque, NM, USA [7]. The collected soil was classified according to the ASTM D2487 –

Unified soil classification system (USCS). The best result was demonstrated by the mix design with addition of hydraulic lime (4% of dry mass of the mixture) and wheat straw fiber (1/5%) cut to the length not more than 15 mm. Need to mention, that selected soils from various locations near Albuquerque were sandy types with low content of the clay which barely meet minimal requirements of plasticity, suitable for extrusion process.

Another study of multinational team evaluated applicability of chitosan and potato starch as stabilizers for mechanical and water durability properties improvement of earth-based matrices reinforced with sisal (agave) fibers. Research showed that earth mix with natural fiber stabilized with chitosan (3%) showed better wettability resistance and water impermeability than those stabilized with potato starch (5%) [8]. No researches of long-term effects of chitosan to mechanical properties and wettability resistance were conducted.



The problem of the shrinkage/cracking were addressed with proposed solution of the quality of earth-printed structures improvement by using of sodium hexametaphosphate (SHMP). Adding SHMP (from 0.55 to 2.2%) showed remarkable results in reducing number of cracks of samples to 0, with replacement 50% of wt. of local soil contend with fine sand [9]. Also, water content for 3D printing mixes can be reduced significantly by increasing the content of SHMP. As stated by authors, this effect can be explained by the dispersant's ability to deflocculate clay microstructures, reducing the interaction strength between clay particles.

Conclusions.

In conclusion it worth to mention that all of researches emphasized the importance of rheological properties of the mixtures – both earth-based and cementitious – to the buildability and mechanical properties of printed structures. Currently in Ukraine, related to the rheology of the mixes – pastes and mortars - regulatory framework (DSTU) limited to terms and definitions, with no methodology recommended. Along with the overall lack of the national and international standards of additive manufacturing in construction, it cause serious impediments in the technology development and implementation in real-scale construction projects.

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Анотація. Огляд сучасних досліджень в галузі адитивного виробництва (АМ) в будівництві - технології 3D-друку з точки зору використання матеріалів на основі ґрунту. Способи адаптації ефективного мікс-дизайну для процесу друку на будівельному майданчику із використанням місцевих матеріалів.

Ключові слова: 3D-друк; екструзія; мікс-дизайн; конструкції з ґрунту.

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