Zero house by 3D printer technology

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Abstract. Implementation of 3D printing technologies into building process is recently one of the most developing sectors. Research teams come every day with new ways of use of this technology. Research is focused on testing thermal – technical properties of certain wall structure built by 3D printing additive technology. Based on results of calculation and measurements will be done optimization of design of mentioned wall structure. The goal of the research is to design wall structure with performance of “zero” house. Another goal is to extend knowledge in area of 3D printing and create new possibilities to better adaptation autonamics 3D printing to building process of the future.

1. Introduction
3D printer technology implementation to building process is currently one of the most dynamically developing sectors. Research groups from all over the world are continuously coming with new ways how to bring this method into actual building practice. This article is mapping current situation of knowledge in this area. It is creating new demands for implementation of mentioned technology and is searching for the answers with help of 3D computer analysis. It then verifies the accuracy of the analysis results by measuring the prototype solution under laboratory conditions. Research results would be optimized wall construction, suitable for direct application on building site with use of autonomous device. This wall would meet the “zero” heat transfer trough the construction parameters (according to STN 40 2020).

FDM (Fused Deposition Modelling) this technology of 3D printing was patented in 1992. FDM is printing method realised by printing head (extruder), which is moving in three dimensional space (axe x, y, z) and prints horizontal layers of materials on each other and the whole object high is growing. By this principle is possible to create device with whom it would be possible to layer wall constructions directly in place of construction and thus to create the building object as if growing from the ground without the need for additional personnel [1].

2. Building process
Currently the 3D printing is used in constructional process in two ways, wall construction prefabrication and creation of monolithic buildings directly on site.

3. Prefabrication
Wall constructions are printed in the production hall and then transported on site where they are completed to building objects. This method is used in WINSUN company (Shanghai - China ). WINSUN built their first building with use of 3D printing tools in 2014. There were years of printing material development behind this first attempt.
2002 – GRG – special plasterboard reinforced with glass fibre
2006 – SRC - special cement reinforced with glass fibre
2006 – FRP – special composite material with glass fibre
2007 – 3D printing of natural stone [3]

4. Construction on site
Building is constructed with help of robotic mechanism directly on chosen site. Such a process greatly reduces the construction costs as well as the construction process time. APIS COR company from Boston in USA is the first company which designed and assembled tool for 3D printing of entire building as monolithic unit directly at the destination. Functionality of their design was verified by printing family house which was finished with additional finishes in 24 hours.

Building was additionally insulated with blown insulation into the outer wall construction envelope. Wall construction is open and made by two closed air gaps, which are continuous in the vertical direction. A narrower gap (closer to the outer surface) is filled with blown insulation after printing is done, thus creating a thermal insulation layer of the wall structure. The gap at the inner edge is reinforced in the horizontal direction by glass-fibre bars (the method of placing these reinforcement elements during the printing process is not known) [4].

Figure 1. Interior of WINSUNs printed house.   Figure 2. WINSUNs wall construction.

Figure 3. House printed in 24 hours by APIS COR.
Figure 4. Cooperation of NASA and APIS COR.

5. Evaluation

Table 1. Advantages and disadvantages

| ADVANTAGES OF BUILDING CONSTRUCTION 3D PRINTING | DISADVANTAGES OF BUILDING CONSTRUCTION 3D PRINTING |
|-----------------------------------------------|--------------------------------------------------|
| Minimal construction waste                   | High initial printer equipment cost              |
| Lower technology costs                         | Little efficient construction                    |
| Less construction workers                     | Little known properties of building materials for printing |
| Safer construction site                        | Need of continuous control during the building process |
| Higher precision                               | Need for additional equipment (fitting of the fillings of construction openings) |
| Possibility of shape changes during construction process without additional costs. | Need to widen and deepen the level of knowledge on the subject. |
| Possibility of estimating exact finish time    |                                                  |
| Less dust production impact on surrounding environment |                                                  |
| Shorter building time                          |                                                  |
| Easier logistic                                |                                                  |
| Little site space requirements                 |                                                  |
| Little material storage requirements           |                                                  |
| Less CO₂ emissions                             |                                                  |
| Less energy consumption for construction       |                                                  |
6. Problem determination
As it is visible from table 1 one of the main disadvantages of 3D printed constructions shows to be little effectiveness of construction. This construction weakness is caused by incorrect shape design of inner wall structure, which is in most examples adapted to create ideal traces for printing head. This way it is shortening building time and it helps to promote the technology of construction.

7. Aim
The aim of research is to design fitting optimization of shape, thickness and inner wall structure with mind on new possibilities, which are offered with use of layer construction printing method. Adjust suitable construction parameters to achieve a heat transfer coefficient $U$ for this construction at the zero-level house level.

8. Zero house
It’s a term which describes very energy-saving efficient buildings, mostly using energy from renewable sources in such amount that during a year they get almost equal amount of energy from environment as they consume. This means that their energy balance is equal to zero or near to zero. [2]

9. Requirements for envelope constructions
According to energy efficiency, buildings are divided into energy classes. By the end of 2015 for new buildings, it was enough to reach the upper limit of class B (global primary energy indicator) for their successful certification. From 1 January 2016 until the end of 2020, it is necessary to enter A1 and after 2020 into A0. [5]

| Table 2. Standardized requirement for building envelope construction. |
|---------------------------------------------------------------------|
| Building envelope structure | Heat transfer coefficient $U$ (W/(m².K)) | Till 31.12.20015 | From 1.1.2016 | From 1.1.2021 |
|----------------------------|------------------------------------------|------------------|--------------|--------------|
| Outer wall, pitched roof with angle above $45^\circ$                |                                          |                  |              |              |
| Flat and sloping roof (up to $45^\circ$), ceiling above the exterior|                                          |                  |              |              |
| Ceiling above unheated space                                       |                                          |                  |              |              |
| Windows and glazed walls, roof windows                            |                                          |                  |              |              |
| Doors without backrest / with backrests                            |                                          |                  |              |              |
| Average U Building (shape factor 0.3 to 1.0)                       |                                          |                  |              |              |
| NED …B                                                              | 0.32                                     | 0.22             | 0.15         |              |
| UNB …A1                                                             | 0.20                                     | 0.10             | 0.10         |              |
| TNB (PD) …A0                                                       | 0.25                                     | 0.15             | 0.15         |              |
| 1.40                                                                 | 1.00                                     | 0.60             |              |              |
| 3.00/4.00                                                           | 2.50 / 3.00                              | 2.00             |              |              |
| 0.39 - 0.58                                                        | 0.27 - 0.38                              | 0.20 - 0.25      |              |              |

10. Current construction
The currently used cross-section of the structure has only minimal thermal insulating properties which greatly reduces its use in the construction of residential buildings.
11. Design
The optimization design of the perimeter structure is inspired by the organic structure of the bone section. Such a spatial structure creates small closed air gaps which greatly reduce the coefficient of heat transfer in the structure. The dense inner mesh forms, similarly to the bone, a support grid on the outer surface, which improves the overall static properties of the element. For better application possibilities of this structure to mathematical models, it is necessary to reduce it to a spatial structure that consists of repeating the same geometric element (Figure 8). The correct design of this structure, the size of the holes in it, and the spacing of the cavities in horizontal and vertical planes will be checked by computer analysis.
Final sample, which will came out of computer analysis as the most appropriate solution, will be made and subjected to laboratory tests for strength and heat resistance. Verification of the design sample confirms or invalidates the accuracy of the computer analysis.

12. Visualization of possible solutions
13. Use
The automated construction system, using the right construction parameters, has wide range of uses. It is possible to apply it on humanitarian missions in areas affected by natural disasters, where it can autonomously create objects from temporary to permanent use. It would also be good to apply this system of construction as one of the possible housing solutions for immigrants, homeless people and unappealing citizens. It is not excluded even its adaptation to the system of individual housing construction where it would be able to cover the needs of so called starting flats.

14. Conclusion
Research of the optimal setting and shape of a wall construction that meets the prerequisites for direct print technology at the building site is the answer to one of the major drawbacks of this construction method. By verifying possible solutions to the problem, it moves the level of knowledge on the subject and creates favourable conditions for the introduction of an automated construction method into building practice.

References
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