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FLUID-DEPOSITION OF ROCKS IS NATURAL MODEL FOR ADDITIVE PRODUCTION

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ABSTRACT

All created in the Nature is the result of natural technology. Solutions from Nature can be incentive for artificial, man's technology of living (biotechnology) and technology of abiogenesis. We have set ourselves the question what is a natural additive model for making parts. After geological analysis and playback of some products of Nature and man-making procedures of additive components was found. Natural model for these procedures to create additive components is the formation of sedimentary rocks 3,75 billion years ago. At the same time we made systematization of additive production and additive manufacturing of these procedures, the first revolutionary change in the primary shaping after 4,3 billion years.

KEY WORDS

natural rocks, natural model of additive processes, additive production, additive manufacturing

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INTRODUCTION

The first additive production process, stereolithography has been introduced by *3D Systems* in 1986 [1]. Only three decades later, additive production is on the way to be a regular process for production of material products from living and non-living substances [2].

Stereolithography (SLA or STL) is an additive production process (generic deposition primary shaping) which employs a vat of liquid ultraviolet curable photopolymer resin and an ultraviolet laser to build parts' layers one at a time [1].

In our time among other trends, one very strong trend is interconnection between biotechnology and technology (of non-living systems). This demands looking into natural technology solutions, to receive ideas for our human, artificial technology. But one trend is underestimated, synthesiological way of thinking. We have too much information, too much partial research, but without the effort to attempt to put this knowledge into new structured cognitive systems.

We try to introduce into our research a synthesiological approach [3]. While describing the history of natural technology for the past 4,4 billion years, we assume to discover the natural model for all deposition procedures of generic, additive production of prototypes, tools, including moulds and more and more, parts and things. This discovery is based on a description – probably the oldest fluid-deposited rocks on Earth, 3,75 billion years old [4].

How do we connect this description with the additive production of parts? According to the origin, rocks can among others sedimentary (depositional) one. At the same time about 95% of additive production procedures of are based on deposition. So, we come to conclusion that natural deposition primary shaping is at least 3,75 billion years old. To support this conclusion, we must make clear difference between the words production and manufacturing.

DIFFERENCE BETWEEN WORDS PRODUCTION TECHNOLOGY AND MANUFACTURING TECHNOLOGY

Production (fabrication) technology is according the systematization given in DIN 8580 [5] and G. Ropohl [6] a common name for processing technology and manufacturing technology[1]. Mostly the procedures of the additive method of making parts are production based. This means that the primary shaping (manufacturing technology) precedes the making of material (processing technology). In clear text, during deposition additive production methods we made first the layers (primary shaping – manufacture technology) which would be than solidified by some chemical reactions like polymerization and/or curing (processing technology). An excellent example for the description of additive production is mentioned SLA procedure [7]. First we must to build up from liquid epoxy resin (substance) a necessary layer (primary shaping – manufacturing) and then followed by a laser-induced polymerization and cross-linking of photo activated resins (processing technology) [7]. Not before the reactions of polymerization and cross-linking are finished, we have no product with necessary application properties [8].

Primary shaping in manufacturing is connected with a given primary shape to produce, but can only occur with a change of the state of materials: solid – liquid – solid. Example of this is process fused deposition modelling – FDM [9-11].

It will be shortly described in the additive production of parts with the aim of visualisation of the difference between additive production and manufacturing technologies, based on the state of the substance.

ADDITIVE PRODUCTIONS OF PARTS

The important revolution in the whole history of the production of parts is primary shaping, without using a cavity in a mould, as means of action. The introduction of computers into the production of parts makes it possible.

We start with the hypothesis that the natural model of the most of generative, additive making procedures (methods) is the fluid-deposition making of sedimentary rocks.

From time of making first natural product, inorganic polymer, zircon 4,3 billion years ago, primary shaping and primary structuring was always in some sort of mould. In the case of zircon the mould was the core of Earth [3].

Additive making procedures (methods) allow the production of parts without a cavity (hollow which is difference between impression and core). For the production of parts by additive procedures we need two steps: preparation of the file with the necessary data as output, and then those data as input transformed into a proper means of action, like 3D-printers.

PREPARATION OF FILES FOR ADDITIVE MANUFATURING

They are two principle modes to prepare the necessary files. The first one is the result of development and design of new part (CAD model). The second way is starting with a real part which would be transformed into necessary file by using 3D scanning [12].

3D scanning is a modern technology that can analyse a real-world object or environment to collect data on its shape and possibly its appearance. There are a variety of technologies for digitally acquiring the shape of a 3D object. A well-established classification divides them into two types: contact and non-contact 3D scanners.

PRODUCTION OF PARTS BY LAYER-BY-LAYER PROCESSES

The basic principle of additive manufacturing is adding material layer-by-layer until the part is finished. Therefore, in literature also can be find term additive layered manufacturing - ALM. This principle is for e.g. opposite of the classic cutting procedures which belong to the group of subtractive processes (turning, drilling, milling, etc.) [12].

Although procedures of additive making parts results with very complicated geometrical 3D shapes of finished parts, generally they are 2½D procedures, in which 2D layers are in general deposited one on each other, and thus a third dimension of the part is achieved [13].

A special characteristic of the additive method of making parts is the fact that the final, physical parts are made directly from the computer 3D data about the part. It is irrelevant what the origin of those 3D data is: CAD design, reverse engineering, computer tomography (CT) or magnetic resonance (MR). From the part's point of view, parts made by procedures of additive making can be considered as a three-dimensional print of the existing CAD data.

Additive making procedures can be divided into a two basic steps: [12]

- generation of mathematical information on layers (virtual environment),
- generation of the layers of physical part (real environment).

The second step is more interesting for this paper, but also for the systematisation of mostly commercial procedures of additive making. In available scientific and professional literature which deals with area of additive making, a lot of many different types of systematisation of those procedures can be found. One of the favourite systematisation of additive making procedures is based on DIN 8580 [5] and DIN 8581 [12] guidelines.

Additive making procedures are classified based type of making (production or manufacturing), state of substances (solid, liquid or gas) – physics and chemistry of the process (Figure 1).

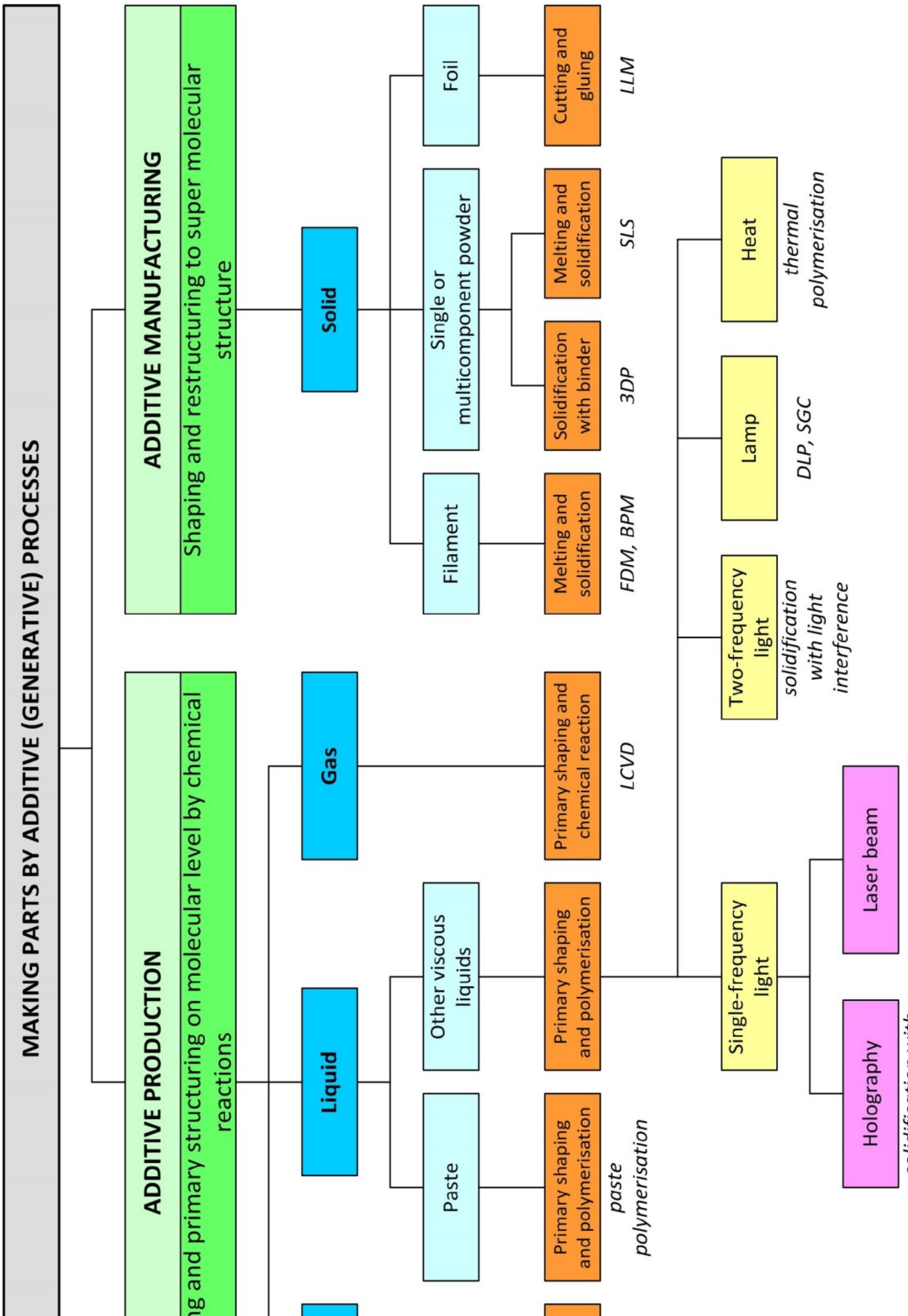


Figure 1. Systematisation of the additive making procedures.

Basically it is possible to summarize systematisation as [12]:

- solidification of liquid materials (polymerisation and/or cross-linking process),
- generating a part from a solid state (cutting of foils and plates; application of partly or completely melted solid materials such as powders and powder mixes – processes of extrusion and laser sintering; bonding of powder particle by binder),
- generating a part from pastose state,
- precipitation from gas state.

EXAMPLES OF ADDITIVE PRODUCTION AND ADDITIVE MANUFACTURING PROCESSES

Stereolithography (SLA or SL) is an example of primary shaping and primary structuring on molecular level, where primary shaping is followed by polymerisation and cross-linking, reactive primary shaping, by laser beam.

Reactive primary shaping we found in processing of thermosets (e.g. epoxy resin), rubbers, ceramics and in some cases during primary shaping of thermoplastics is like the casting of poly(methyl methacrylate) (PMMA) [8].

Primary shaping in manufacturing is connected with a given primary shape to the product, but only occurs with a change of the state of materials: solid – liquid – solid. An example of this is Fused deposition modelling – FDM. The solid polymer filament is supplied to the machine through a nozzle, which is computer-controlled and in one layer it forms the raster of the item in the respective layer. The material exits the nozzle in liquefied/softened state and at ambient temperature solidified quickly to solid body. The entire system is usually in a heated environment. After making the first layer, the working bed is lowered for the thickness of the new layer and the new layer is extruded [9-11]. In more complex product geometry, the support structure may be used. In this case a double extrusion head is used. It is possible to extrude PE-HD, PE-LD, PP, ABS and also biocompatible and/or biodegradable materials (e.g. polycaprolacton – PCL) and elastomers and it is possible to simultaneously produce several prototypes. FDM can also produce support structure made from same material as product and with one head only. Support structure in this case and at the end of production is removed mechanically [11, 14, 15].

The described procedures are in principle deposition one. We try to proof our hypothesis. Is possible the natural model of additive making of parts fluid-deposition of rocks? This idea has been proved first by geological analysis.

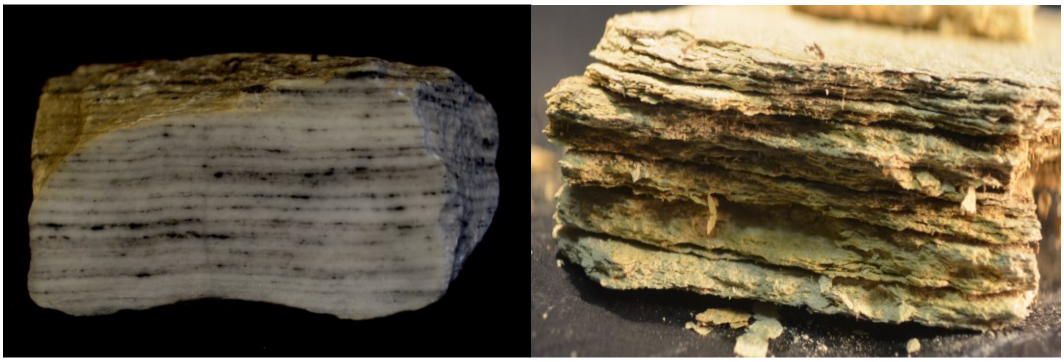
GEOLOGICAL ANALYSIS

During this analysis we study two examples of sedimentary rocks [16, 17].

Starting from the assumption that the sedimentary rocks are a natural model for making a product by additive processes, there been found two examples, gypsum and pelite sedimentary rocks.

Figure 2a shows a hand sample of gypsum, very common evaporate sedimentary rocks. The sample is from the site of Mali Kukor from Southern Croatia, where gypsum was deposited at the end of the Paleozoic Era in the Upper Permian meaning 250-260 million years ago [16].

Figure 2a clearly expressed horizontal lamination (thickness thinner than 1 cm) and is an indicator of seasonal changes in the conditions of deposition. Lighter laminae are composed of gypsum (inorganic polymer), while darker laminae with plaster containing higher amounts of organic matter. Precisely it is the inorganic-organic composite creation.



a) b)

Figure 2. a) the sample of horizontally laminated gypsum from the site of Mali Kukor (age 250-260 million years) [16], b) the hand sample of horizontally laminated pelite sedimentary rock from the site Voćin 12 million year old [17].

Figure 2b shows hand sample of pelite sedimentary rock from Voćin locality, Eastern Croatia, composed of alternate laminae of silt and marl. The rock is an inorganic polymer with a well-defined horizontal lamination deposited in the Middle Miocene Epoch, about 12 million years ago [17].

An important property of sedimentary rock is the arrangement in the layers, in our case, the most interesting is the horizontal layering (lamination). Which indicates that the initial assumption that the natural model for additive production, formation of sedimentary rocks is acceptable.

We decided to proof our hypotheses using CD scanning equipment, 3D printers and used geological materials.

EXPERIMENTAL PROOF

Using three different types of printers and different materials for printing we produce parts which demonstrate the origin of additive production and we made a comparison with historical materials found in the nature.

MATERIALS AND EQUIPMENT

We used for scanning following cameras: ATOS II (procedure A), AVT Guppy F080B FireWire 400 camera (procedure B) and ATOS Core 135 (procedure C).

In Table 1 is given some technical specifications of 3D printing devices for all cases (A, B and C) which is shown in Figure 3a - f.

PROCEDURE A

The rock specimen originating from Ilidža, Bosnia and Herzegovina and exported scan made with non-contact 3D scanner ATOS II is given in Figure 3a and 3d [17, 18].

The scan presents the rock called aragonite. Prismatic crystals of mineral aragonite ($CaCO_3$, polymorphic modification) originated from hydrothermal solution at low temperatures (60 °C).

Aragonite is a very unstable mineral and is easily converted into more stable calcite ($CaCO_3$). Brown – yellow colour of aragonite comes from the presence of Fe oxide and hydroxide – (limonite).

Because of the bright colour of the rock, it is difficult to notice the layered texture of the real material. After the polygonization, created CAD model can be exported into the some software for next analyses or printing.

For producing the replicas in the procedure A the material used has been a kind of composite material based on blaster compounded with binder. After each layer, the substances must to react with the binder. After this description of used materials and the necessity of reaction, give us right to call this procedure the production one.

The replicas has been successfully made, however, due to the type of available material, the printed layers are not clearly visible, so the replica missed here [18].

Table 1. Technical specifications of 3D printing device.

Technical specification	Procedure A	Procedure B	Procedure C
Procedure used	Z 510	*Zprinter 450*	*PolyJet*
Reactive procedure, yes-no	yes	yes	yes
Build speed, layers/min	2	2	
Layer thickness, mm	0,089-0,203	0,089-0,102	0,016
Resolution, dpi	600 × 540	300 × 450	600 × 600 × 1600
Material options	High-performance Composites, Casting Materials, Elastomeric Material	High-performance Composites	Photopolymers
Material used	Composite material (USA)	Composite material (USA)	VeroWhite (Izrael)
System software	ZPrint	Z Corporation's proprietary software accepts solid models in STL, VRML PLY, and 3DS file formats as input. ZPrint™ software features 3D viewing, text labelling, and scaling functionality	Objet Studio for Connex 350
Input formats	STL, VRML, PLY and 3DS	STL, VRML, PLY, ZPR and 3DS	STL, OBJDF, SLC
Printer	Z 510	*Zprinter 450*	*Connex 350*
Printing system	inkjet layer printing system	inkjet printing system	UV hardening

PROCEDURE B

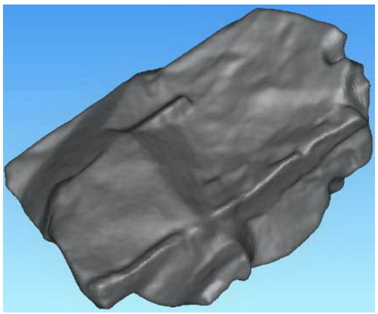
For second test procedure we found specimen from a place in the pedestal of a mountain in Vlašić, Bosnia and Herzegovina (Figure 3b). This rock has been collected for making stone tools during an education process at the University of Zagreb, Department Archaeology. The material of the stone is chert, sedimentary rock originating from radiolarite of Triassic or Jurassic time.

The basic material for printing was composite material (USA), a fine powder based on calcium carbonate ($CaCo_3$) with organic additives in solid state. The powder is bonded during printing process with a binder (adhesive) (USA) from the inkjet print head. ZPrinter 450 uses Drop-on-demand inkjet printing method.

Zprinter 450 creates 3D models by binding composite material using heat-activated printing additive and adhesive material. This method is frequently referred as reactive printing procedure (Figure 3e).

For the 3D scanning purpose Mephisto Basic 3D scanning system was used. Final version of the scanned model was created with MeshLab open source software and exported to WRML format [19, 20].


a)


b)


c)


d)


e)


f)

Figure 3. a) specimen of rock aragonite, originating from Ilidža, b) rock's specimen from Vlašić scanned by *AVT Guppy F080B FireWire 400* camera, c) specimen of original stone shave from Mujina cave scanned by *ATOS Core 135*, d) 3D model of scanning Ilidža's rock by *ATOS II*, e) printed specimen from Vlašić with *Zprinter 450*, f) stone shave from Mujina cave printed by *PolyJet* printer.

PROCEDURE C

Figure 3c represents possibility of additive technologies in archaeology. This is stone shave from Mujina pećina (cave), site near Split, South Croatia and is 41,000 year old. Stone shave was made by Neanderthals from stone chert.

Chert is microcrystalline or cryptocrystalline sedimentary rock material composed of silicon dioxide (SiO_2). It occurs as nodules, concretionary masses and as layered deposits. Chert breaks with a conchoidal fracture, often producing very sharp edges [21] therefore Neanderthals used it for cutting tools.

For the possibility of getting sharp edges and surface with small roughness PolyJet process was used. ATOS Core 135 was used for scanning and for additive manufacturing Connex 350. Material was white acrylic photopolymer.

Figure 3c shows the original stone, and 3e printed. In the Figure we can observe sharp edges and smooth surface. On the printed product it can't be seen layers because Polyjet process produces layers of 16 μm thickness.

CONCLUSION

The specimen's researchers found of rock gypsum and pelite encouraged researchers to scan mode two mineral from other substances. Scanning and procedures described in additive production have been proven to be a natural model of additive production that began before 3,75 billion years ago. It should be noted that the development of additive production without moulds, back in 1986 is the first revolutionary change in the primary shaping of parts, since the making of zircon formation period, 4,3 to 4,4 billion years ago.

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REMARK

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