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Construction Innovation: Support for 3D Printing House

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***Abstract*—**Contour processing is the new technology challenge for architects and construction companies. The many advantages it promises make it one of the most interesting solutions for construction in terms of automation of building processes. The technology for 3D printing houses offers many application possibilities, from low-cost construction, to being considered by NASA for visionary projects as a good solution for building settlements on other planets. Another very important point is that clients, as architects, will no longer have many limits in design concerning ideas and creativity. The prices for real estate are constantly increasing and the lack of availability of construction materials as well as the speculation that has been created around it in 2021 is bringing prices to such a level that in the future it will be difficult for developers to find customers for these ultra-expensive homes. Hence, this paper starts with the introduction of 3D printing, which now has the potential to gain an important position in the market, becoming a valid alternative to the classic construction process. This technology is not only beneficial from an economic point of view but it is also a great opportunity to have an impact on the environment by reducing CO_2 emissions. Further on in the article we will also understand if, after the COP 26 (2021 United Nations Climate Change Conference), world governments could also push towards building technologies that reduce the waste materials that are needed to be disposed of and at the same time reduce emissions with the contribution of governmental funds. This paper will give us insight on the multiple benefits of 3D printing and emphasize the importance of finding new solutions for materials that can be used by the printer. Therefore, based on the type of material, it will be possible to understand the compatibility with current regulations and how the authorities will be inclined to support this technology. This will help to enable the rise and development of this technology in Europe and in the rest of the world on actual housing projects and not only on prototypes.

***Keywords*—**Additive manufacturing, building development building regulation, contour crafting, printing material.

I. Introduction

THE automation in the world of construction is nothing new. Man has long since tried to build mechanisms that could help speed up the construction of houses. We find confirmation of this back in 1941. A patent was registered for a rudimentary 3D wall building machine printer invented by William E. Urschel called the "Urschel wall building machine" [1]. To understand better the similitude with the modern 3D printer, a video of this machine in action is available online on YouTube [2]. The development of this construction system, devised by Urschel has evolved through the use of computers in design and the modern technology available to us today. Various companies have managed to create mega-printers capable of building houses in a matter of days. These printers have the bigger advantage of using less materials compared to the ordinary methods, giving endless design possibilities and employing specialized people on site which does not have to only be represented by men, but also by women. In fact, this technology also gives women the opportunity to enter the construction world, which has always been a purely male environment. This technology can change the employment market so much considering also another very important aspect represented by a great opportunity in terms of social integration rights for people with disabilities being able to participate in the construction process as a print operator to supervise and control the printer during work. What is impressive about these mega-printers is that we are able to produce external and internal walls at the same time, as opposed to the use of the first printers, which could only print components that were only later brought to the construction site and assembled.

In recent years, the companies producing these printers have made some prototype buildings using different types of materials, and only in the last few years have examples of printed houses some been made with a regular building license, which could be sold like any house built with traditional materials. This is because we must not forget that the printer remains and will always be just a tool. The real challenge at the moment for this technology is to find a place in the housing market using recognized materials that are tested and approved by the local authorities for the necessary permits for construction.

The article will help to better understand the technology and its benefits by trying to understand what support points are needed for this technology to get off the ground.

II. Study Prototypes vs Permitted Constructions

Since 2017, there have been many examples of prototype houses made with 3D technology and many more will be added to the list. Initially, the prototypes were only made to make people understand how printers work, how fast they can be made, their versatility and their limitations, which perhaps have not been fully understood yet.

It is only in recent years that manufacturers, having perfected the software and mechanical parts of their printers, have begun to address the problem of the reason for their

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creation: making houses.

It is easy to understand that, printing a 20sqm house in your own backyard is not the same thing as printing a 3D house in compliance with regulations where a family will have to live.

Although these printers have all the necessary certificates for their sale and marketing, they are actually experiencing a slowdown in sales due to a much bigger problem: the lack of information about the material to be used. While it is true that technology can make giant strides in a matter of weeks, we also know that bureaucratic problems can take years to resolve. In fact, today, even if we have the tools to print houses, the real problem is the lack of technology for the materials that can be printed.

To simplify the concept let's take this example: would you buy a Ferrari without knowing what type of petrol you needed to run the engine on? Would you buy it knowing that there is no petrol on the existing market to get it started, and thus the impossibility of driving it? Probably no one would buy a Ferrari to keep it sitting in the garage. Well, we are in a very similar situation even if it sounds almost absurd.

If you wanted to buy a 3D printer today, you would have a good choice of companies that are at a very advanced stage in this technology, and you would certainly receive a response in no less than a week. But if you ask these companies about the materials to be used for the printers, even if they give you some basic information, they only sell you the tool and nothing more. At this point you realize that it is impossible to find a price for the materials that you can use with your 3D printer. In fact, you don't even know where to buy it. Even if there are some companies that sponsor the sale of printer materials, there is no price list in the technical specifications that you can access. The only way to have access to this information is to contact these companies directly and hope they will respond to you.

As already explained, printers are only tools, and it is necessary to understand that in reality these tools are limited by the poor availability of materials, and the weak information available on them.

III. Printing Material

These days, we can consider that the characteristics of 3D printer technology are based on two main points:

A. The characteristics of the material used for printing
B. The ability of the printer to use the material chosen for printing

Of the points mentioned, only the second can be considered a problem that can be technically solved by the printer manufacturer. Only the first point can be defined as the true Achilles' heel of this technology.

It is precisely on the material that a lot of research is being done today to try to find an ideal formula. Everything focuses on the consistency of the material, its resistance and the speed of curing. These factors are very sensitive to the characteristics of water and the influence of heat, cold and humidity, which change from region to region in every part of the world. This means that, theoretically, the possibility of using materials from these instruments is unlimited. The only limitation therefore depends on the composition of the material to be used and its technical-mechanical characteristics in order to obtain the necessary certifications for use in construction. Cement is not the only material that can be printed. Multiple materials may be used, such as metal, plastic, foam, geopolymers and natural materials that the company WASP has used as well. The 3D construction GAIA uses is composed of 25% of soil taken from the site (30% clay, 40% silt and 30% sand), 40% from straw chopped rice, 25% rice husk and 10% hydraulic lime [3].

The most common material used and able to give the most elegant and most recognizable aesthetic effect (toothpaste effect) is the dry mortar mix. However, this new-generation material still has many unknowns before it can be used on a larger scale. If we look at the example of the printed house in Beckum, Germany, the only way to sponsor this house, as the first house with a building permit, was through a collaboration with the Technical University of Munich and the engineering firm Schiessl Gehlen Sodeikat. They had to carry out all the necessary tests to supply the local authorities with the necessary documentation to receive permission to use this material [4] [5]. The structures of printed houses generally present themselves very well, although in certain places they may have defects or cracks that need to be understood in what way they can be removed, without making the repair visible and not having complaints from the customer (Fig. 1).

Fig. 1 Crack in the dry mortar wall

Only with time will we be able to understand the merits and flaws of this material, although certainly the biggest flaw is the price, which is around 1000 euro per m^3 [6].

It is easy to see that if we were to build all over the world, a lot of money would have to be invested in the development and research of this material in order to be able to use it officially in construction and obtain permits. If we extend this principle to all the materials that the printers could use, it becomes clear that it will still take many years before we can enjoy the multiple benefits of this technology. Then a question arises: why not use the old and dear classic cement where all the characteristics are known in the construction field? We

used it in hundreds of examples in the 1950s during the Brutalism period and continue to use it for large constructions such as skyscrapers and bridges. It is certainly a material well known to architects, engineers and authorities from all over the world.

It is precisely from this idea that the company COBOD started. To date, the possibility of being able to expand the use of 3D printers on a large scale is precisely due to this simple and ingenious possibility of making concrete printable. The Danish company owns a patent on an additive called D.FAB (Digital Fabrication) that allows this material to be used by printers as well. The advantage lies in the fact that 99.5% of materials are locally available, with only the additive that is procured by the COBOD Company [7]. A comparative study has been carried out in terms of costs between the use of dry mortar mix and the use of classic cement with D Fab by the German university in Oman (GUtech University), and the results are very satisfactory. The use of cement is able to significantly reduce construction costs. According to the publication, the cost for the construction of the vertical elements in concrete was 1,600 euros instead of 20,000 if it had been made with dry mortar mix [8]. If we add the enormous economic advantage and the well-known technical characteristics of cement, we could really consider this to be a turning point for this technology. We have been testing concrete for years, and we are well aware of its resistance and breaking characteristics. It also means that everything related to what it takes to build and obtain the necessary permits could become much simpler. Certainly, the aesthetic finish of the concrete's raw material is not as appealing as that of the dry mix mortar, but it still opens the way for 3D house constructions to be competitively priced on the market, and it also makes it easier for the authorities to obtain the necessary certification. The characteristics of the material for the 3D printed houses and its durability are unknown, contrary to the characteristics of classic materials such as concrete.

IV. Regulation

As is now well understood, the material used by 3D printers is the real limitation for the acquisition of certifications. And if there are no certifications, we will never have the possibility of expressing the full capabilities of this technology. Certainly, the use of this technology to this day is a valid alternative to consider for the first buildings outside of Earth. For NASA, it is an excellent technology that allows them to consider the possibility of building the first houses on Mars, as this technology lends itself very well to this type of goal [9]. NASA has always had access to funds that have given it the opportunity to experiment with new technologies, and certainly no one on Mars will ask for building permits.

It is unclear whether we can consider these constructions safe, how the new material will react in the coming years, and how we could fix the problems of cracks that will arise in the future. Furthermore, we do not know how in the future if we want to change the layout of the rooms how we should do it, and how the contractor can give guarantees of the building to his clients.

The non-existent precise formula for printer material and the changes and development done every month by companies makes the answer to these simple questions very difficult. That is why we understand why there is a lack of certification for each material. This should not become an excuse to justify this lack, but rather a wake-up call. Now, this technology is a reality and it is inconceivable that there are no guidelines to follow for its use. The major printer companies should start collaborating with authorities and try to create specific guidelines together to guarantee customers, interested in 3D houses, a safe and quality product. There will be people living in these houses, investing their life savings, going into debt to realize their dream, and so we have to make sure that these houses are beautiful, innovative and above all safe.

V. Truth against Lies

Nowadays, after the peak of inflated expectation that create attention around this technology, we can begin to better understand the true benefits of these printers.

Let us begin by explaining that houses made with 3D printers cannot be considered completely environmentally friendly because of the cement-based mixture used. What makes the technology ecological is the ability to use much less material compared to a house made with the classical method. An important point is that the printer actually uses only the material needed for printing, and consequently creates only a few m^3 of waste. Another fact on the debris is that by creating the systems in the cavity of the walls, the breaking phase of the finished walls to create the water, electrical and drainage systems is no longer foreseen. Therefore, this also participates in the reduction of debris, and the States should support this construction with incentives.

Considering climate change, and everything that was discussed during the United Nations Climate Change Conference COP 26, we could include this technology in the list of alternatives to reduce construction site waste. The fact that it does not use environmentally friendly materials (for the time being), but instead can help reduce the production of cementitious material, gives the use of this technology the right to be supported and sponsored by States.

Although many people will disagree, we have to consider that for some sectors it will be very difficult to push on 100% environmentally friendly technologies, then at this point we can focus on technologies that are able to decrease the use of non-ecological material but do not eliminate it.

Let's try to make a very easy comparison. Today, anyone who exchanges a car that uses fossil fuel for an electric car receives benefits, such as not having to pay for parking or gain access to certain areas of the city that are closed to combustible cars. These are some of the reasons that have helped to change consumer opinion on electric cars: the support of the authorities for a technology. Not to be forgotten is the enormous marketing communication that based on the ecological factor has guided many consumers to use these vehicles. However, let us not forget that the electric cars that do not pollute are creating enormous damage to the climate, environment and human rights due to the production of their

lithium, nickel and cobalt batteries [10].

We are and always will be a population heavily dependent on fossil materials and it will be very difficult to achieve 100% of eco-sustainability in the construction field.

Obviously, with an eye on the future of more ecological constructions with 3D printers, a change is being attempted with the use of geopolymers. Unfortunately, not all printers are capable of using this material and many tests will still have to be carried out in order to bring this material to a large-scale use, not forgetting the economic aspect, as it is not exactly a cheap material.

Another very inaccurate piece of information is that these constructions are not expensive. In reality, it all depends on the material used for printing. For example, dry mortar mix doubles the cost of 3D constructions when compared to ordinary materials. In contrast, in the case of classic concrete, with the addition of an additive, the constructions are cheaper and can reduce costs by up to 50% compared to classic materials.

Another not entirely clear point is when we hear that we can build a house in a few hours. This is not the absolute truth. Normally, the companies publish the time that the machine needs to print the layout of the house, considering only the quantity of material to be printed and the printing speed of the machine. This only works in theory because, in reality, during printing we need to make the electrical systems, water systems, structural reinforcements, installation of the insulation and all the other factors that are needed for the construction of a habitable house.

VI. Conclusion

Surely, the present day's technology of 3D printers for homes is not yet ready for its development on a larger scale.

Unfortunately, the lack of regulations on these structures lead to the creation of prototypes scattered here and there around the world and only a few examples of real construction. In these few cases it was the designers who found a way, in collaboration with the local administrations, to create the first houses with building permits used as homes and not just as technological examples:

- Eindhoven Milestone Project: The Europe's first inhabited 3D-printed house [11].
- PERI and COBOD's German: First 3D-Printed Residential Building in Germany [12].
- SQ4D INC: First legally permitted 3D printed house in the USA for sale online through Zillow [13].

The use of the dry mortar mix does not allow a wide use precisely because research on this material is still necessary. In light of what is shown, it is necessary to understand if it still makes sense to do a lot of research on the dry mortar mix or if it will be vital to change the course of the use of this material. It will be difficult to find interest in a technology that costs around twice as much as traditional materials.

Everyone will prefer to use ordinary building materials by taking advantage of robotic support to speed up construction. At that point, the development of 3D printers will have a difficult time. If, on the other hand, we focus on the real possibility of making quick and cheap constructions, with considering the cost of land, surely something that finally brings costs down will be very convenient for many consumers.

The turning point could be the use of classic concrete. Being a material with well-known characteristics, it could bring the end of the curve called "trough of disillusion" closer and be able to accompany us into the "slope of enlightenment" phase of the Gartner curve for emerging technologies (Hyper Cycle) where you can see the first steps towards standardization of the materials used in 3D printers, the definition of regulations with the use of classic cement aimed at the growth phase of productivity "plateau of productivity" and the globalization of this technology (Fig. 2).

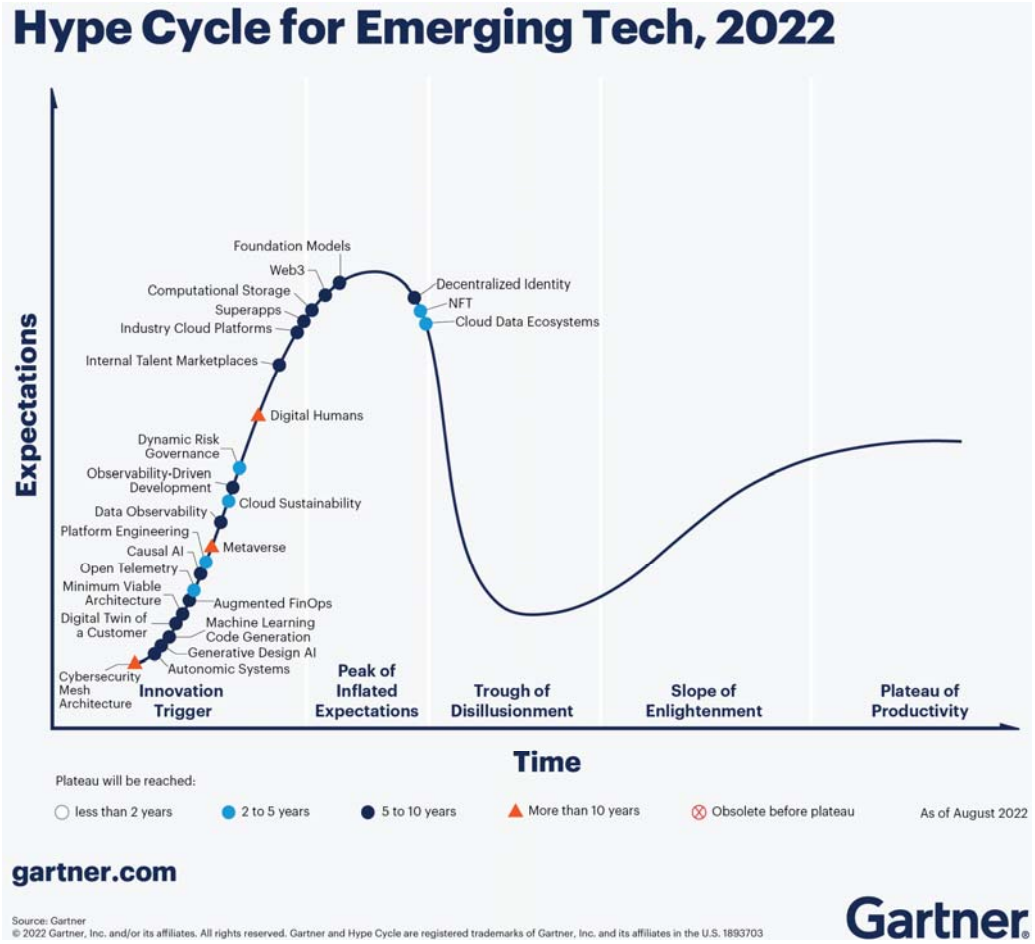

Fig. 2 Gartner Hyper Cycle graph for emerging technologies [14]

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