ANALYSIS OF 3D PRINTING AS PART OF THE PRODUCTION PROCESS IN THE AUTOMOTIVE, AEROSPACE AND CONSTRUCTION INDUSTRY

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Contents

1 Introduction

3D printing has proved to be an interesting technology having the potential to change the manufacturing industry. The objective of this document is to prove if this technology is suitable for the construction, aerospace and automotive industries and the use of it in them.

When we think about 3D printing, we usually think about prototyping or modelling. There are a lot of examples of the use of this technology for this purpose. However, the additive manufacturing has begun to be an attractive assent in these industries. Being able to produce a something directly from a 3D design with suitable properties is something to take into account. Also, have some trending such us rapid manufacturing that is already being used for big companies and generating a lot of revenue out of it.

These topics will be addressed in this document as well as some interesting uses of 3D technology that can lead to the development of this technology in the industrial field.

2 Research Methodology

This section will be dedicated to the explanation of the methodology followed to search, obtain and analyse the papers used in this project.

First thing we should address when we are starting a project are the research questions. In this case, the objective was to find if 3D printing was suitable to use in companies belonging to different fields such as construction, aerospace and automotive industry.

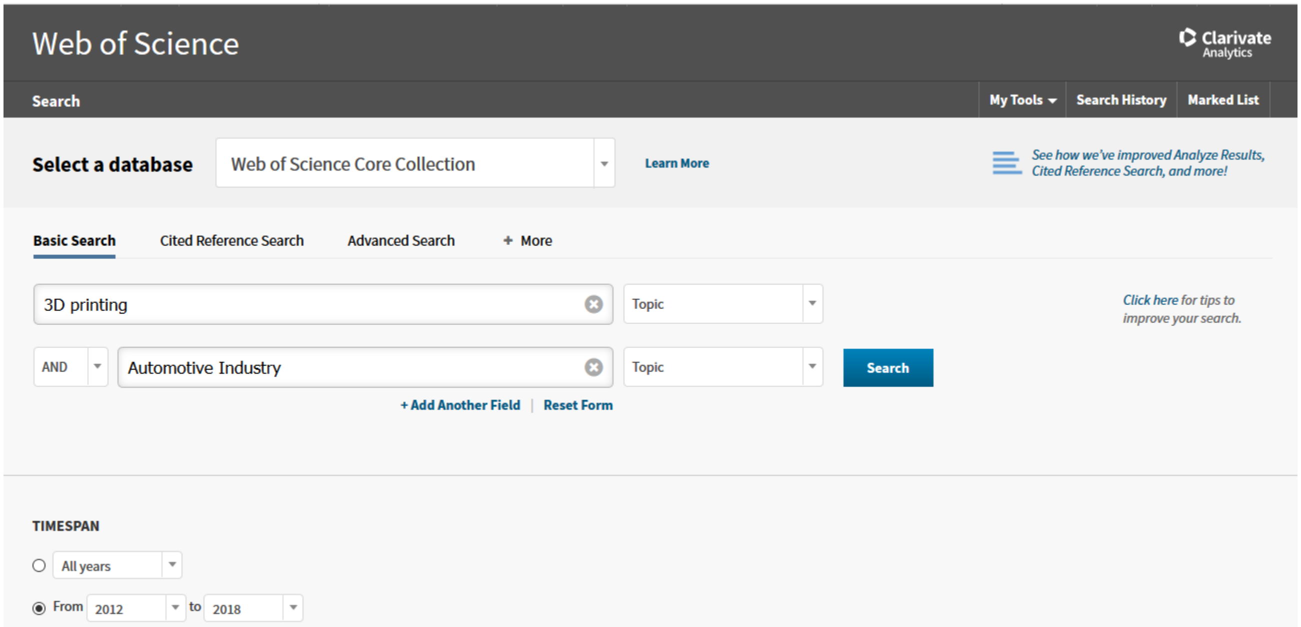
In order to achieve this objective it is important to do a proper literature review. The methodology followed in this paper starts with a general research in *Web of Science* and then it follows analysing all the data that was found there with *Hammer*.

Once you have the data from Hammer, you can use it in *KH Coder* in order to analyse the content of the abstracts and refine your research.

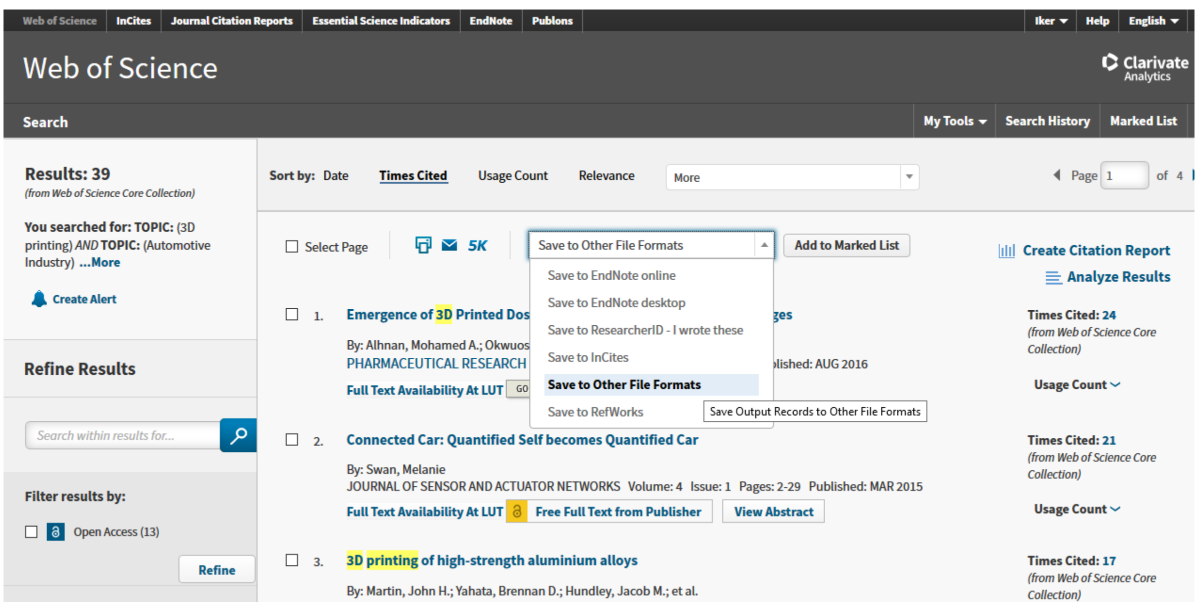
2.1 Web of Science

In this project, the *Web of Science* has been used due to the fact that it has a good coverage of papers. It is less than others such us *Science Direct*, but it is enough for this project.

The process followed here is simple, we just have to search for the information that we are interested in. It is a good idea to adjust the timespan in order to not get outdated. However, most of the papers in the field of 3D printing are written in the last 5 years approximately.



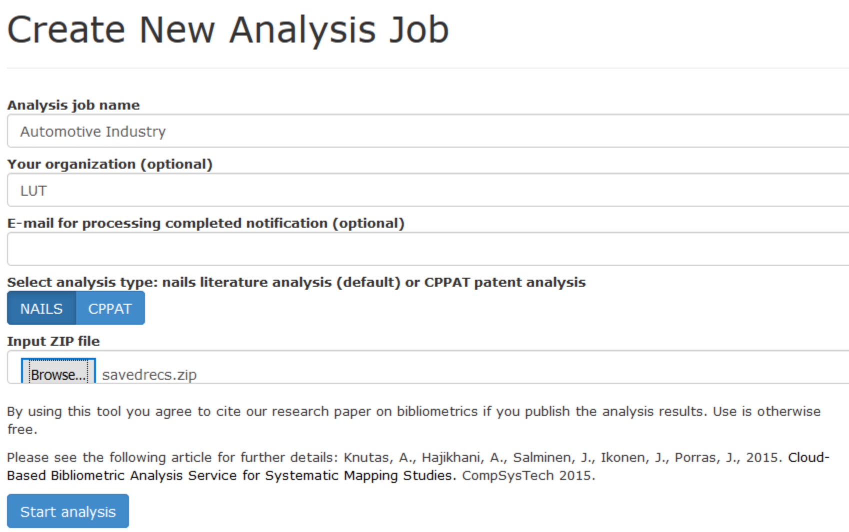
In this case, we have 39 results. There is no need to order the data with any criteria because we will download all the scope and analyse it completely.



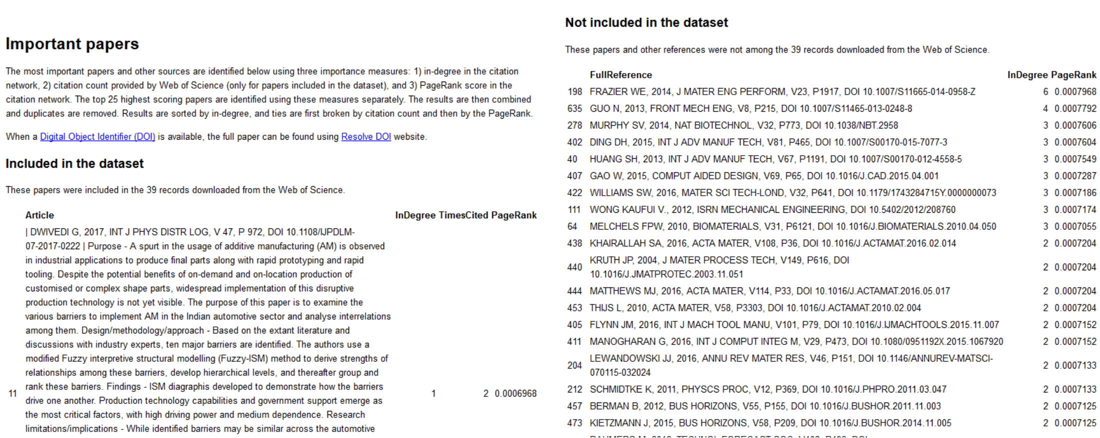
Hammer needs an special format in order to be able to analyse the data. We need to download all the information about the papers in *Tab-delimited (Win, UTF-8)*.

2.2 Hammer

When we have all the data about the general scope, our objective is to determinate which paper is more relevant in order to optimize the research time.



Hammer allows us to run an analysis that will tell us some interesting information such us most important authors in this field, most relevant papers inside the scope or even most relevant papers related to our research out of the scope.



Important papers

The most important papers and other sources are identified below using three importance measures: 1) in-degree in the citation network, 2) citation count provided by Web of Science (only for papers included in the dataset), and 3) PageRank score in the citation network. The top 25 highest scoring papers are identified using these measures separately. The results are then combined and duplicates are removed. Results are sorted by in-degree, and ties are first broken by citation count and then by the PageRank.

When a Digital Object Identifier (DOI) is available, the full paper can be found using Resolve DOI website.

Included in the dataset

These papers were included in the 39 records downloaded from the Web of Science.

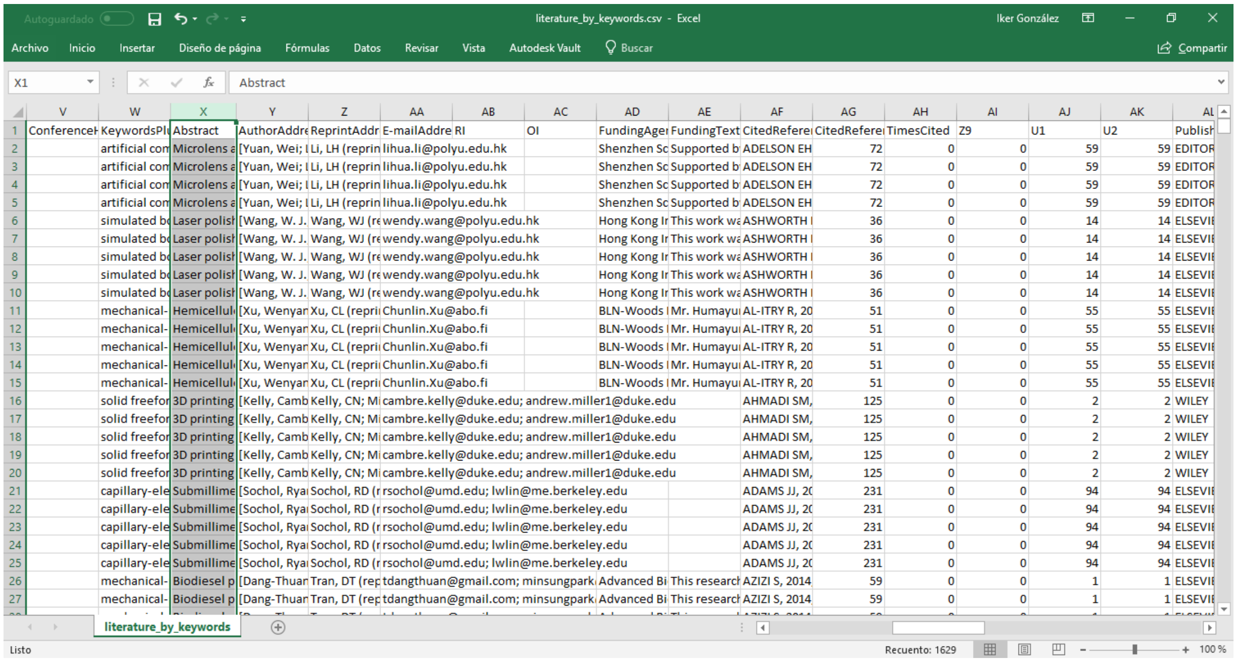
	Article	InDegree	TimesCited	PageRank
11	| DWIVEDI G, 2017, INT J PHYS DISTR LOG, V 47, P 972, DOI 10.1108/IJPDLM-07-2017-0222 | Purpose - A spurt in the usage of additive manufacturing (AM) is observed in industrial applications to produce final parts along with rapid prototyping and rapid tooling. Despite the potential benefits of on-demand and on-location production of customised or complex shape parts, widespread implementation of this disruptive production technology is not yet visible. The purpose of this paper is to examine the various barriers to implement AM in the Indian automotive sector and analyse interrelations among them. Design/methodology/approach - Based on the extant literature and discussions with industry experts, ten major barriers are identified. The authors use a modified Fuzzy interpretive structural modelling (Fuzzy-ISM) method to derive strengths of relationships among these barriers, develop hierarchical levels, and thereafter group and rank these barriers. Findings - ISM diagraphis developed to demonstrate how the barriers drive one another. Production technology capabilities and government support emerge as the most critical factors, with high driving power and medium dependence. Research limitations/implications - While identified barriers may be similar across the automotive	1	2	0.0006968

Not included in the dataset

These papers and other references were not among the 39 records downloaded from the Web of Science.

	FullReference	InDegree	PageRank
198	FRAZIER WE, 2014, J MATER ENG PERFORM, V23, P1917, DOI 10.1007/S11665-014-0958-Z	6	0.0007968
635	GUO N, 2013, FRONT MECH ENG, V8, P215, DOI 10.1007/S11465-013-0248-8	4	0.0007792
278	MURPHY SV, 2014, NAT BIOTECHNOL, V32, P773, DOI 10.1038/NBT.2958	3	0.0007606
402	DING DH, 2015, INT J ADV MANUF TECH, V81, P465, DOI 10.1007/S00170-015-7077-3	3	0.0007604
40	HUANG SH, 2013, INT J ADV MANUF TECH, V67, P1191, DOI 10.1007/S00170-012-4558-5	3	0.0007549
407	GAO W, 2015, COMPUT AIDED DESIGN, V69, P65, DOI 10.1016/J.CAD.2015.04.001	3	0.0007287
422	WILLIAMS SW, 2016, MATER SCI TECH-LOND, V32, P641, DOI 10.1179/1743284715Y.0000000073	3	0.0007186
111	WONG KAUFUI V., 2012, ISRN MECHANICAL ENGINEERING, DOI 10.5402/2012/208760	3	0.0007174
64	MELCHELS FPW, 2010, BIOMATERIALS, V31, P6121, DOI 10.1016/J.BIOMATERIALS.2010.04.050	3	0.0007055
438	KHAIRALLAH SA, 2016, ACTA MATER, V108, P36, DOI 10.1016/J.ACTAMAT.2016.02.014	2	0.0007204
440	KRUTH JP, 2004, J MATER PROCESS TECH, V149, P616, DOI 10.1016/J.JMATPROTEC.2003.11.051	2	0.0007204
444	MATTHEWS MJ, 2016, ACTA MATER, V114, P33, DOI 10.1016/J.ACTAMAT.2016.05.017	2	0.0007204
453	THIJS L, 2010, ACTA MATER, V58, P3303, DOI 10.1016/J.ACTAMAT.2010.02.004	2	0.0007204
405	FLYNN JM, 2016, INT J MACH TOOL MANU, V101, P79, DOI 10.1016/J.IJMACHTOOLS.2015.11.007	2	0.0007152
411	MANOGHARAN G, 2016, INT J COMPUT INTEG M, V29, P473, DOI 10.1080/0951192X.2015.1067920	2	0.0007152
204	LEWANDOWSKI JJ, 2016, ANNU REV MATER RES, V46, P151, DOI 10.1146/ANNUREV-MATSCI-070115-032024	2	0.0007133
212	SCHMIDTKE K, 2011, PHYSCS PROC, V12, P369, DOI 10.1016/J.PHPRO.2011.03.047	2	0.0007133
457	BERMAN B, 2012, BUS HORIZONS, V55, P155, DOI 10.1016/J.BUSHOR.2011.11.003	2	0.0007125
473	KIETZMANN J, 2015, BUS HORIZONS, V58, P209, DOI 10.1016/J.BUSHOR.2014.11.005	2	0.0007125

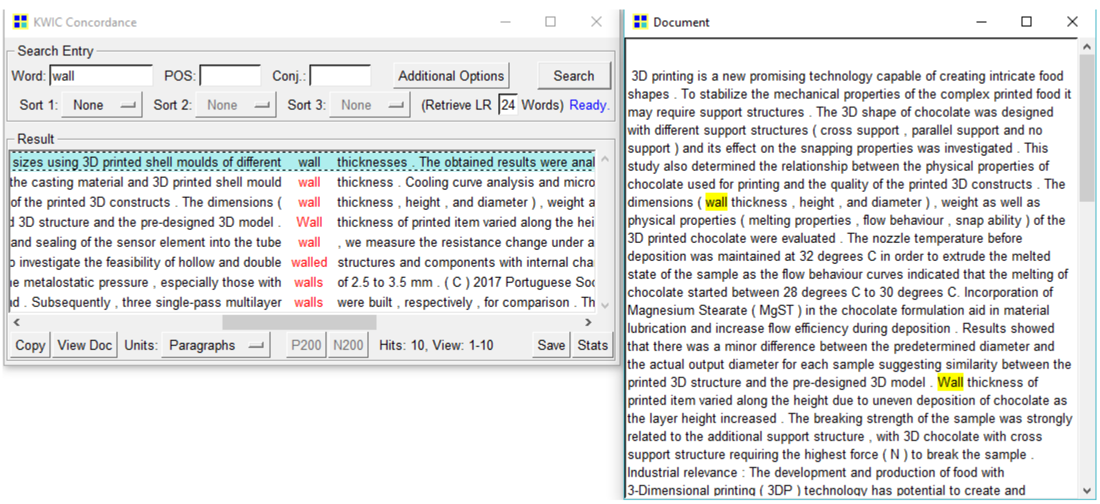
Once we have the information given by *Hammer*, we can read and analyse the most important papers related to our research. 1 In addition to that, we can download the analysis results in csv format.



This results give us the abstracts of every paper in the scope in a format that *KH Coder* can read and analyse.

2.3 KH Coder

The use of this program is due to its analysis capabilities. Once you know how to use it, it makes the refinement of the scope much more easy.



3 Construction Industry

The main uses of 3D printing in this industry have been modelling (including study models or prototyping) and manufacturing. This last category has been gaining weight over the years and we will focus on it.

3.1 Modelling

There are different types of modelling, but we will not go further in this field.

- Study models. (prototyping)
- Competition models.
- Promotional scale models.

(Sculpteo, 2018 (accessed March 26, 2018))

3.2 Manufacturing

This manufacturing could be the next standard when it comes to construction. We would be able to create buildings with an intricate design using only 3D printing.

It is also named Rapid Prototyping. This name describes the time saving associated with the negation of the human modeller, or tool maker employed to create the object for evaluation as part of the design process. Rapid Manufacturing is the term applied when Rapid Prototyping machines are used to produce end use parts directly.

It should also be noted that, contrary to the name, Rapid Manufacturing is not concerned with speeding up manufacturing process; it simply eliminates the need for tooling and so shortens time to manufacture.

A principle driver for Rapid Manufacturing is product customisation and/or personalisation at no extra cost.

Advantages of this technology:

Integration of mechanical and electrical services within the structure means reduced amounts of wasteful and time consuming builders work.

Better control over the deposition of build material will result in better internal and external finishes, completed as the structure is built.

Being able to consider the structure as a homogenous unit will negate the need for difficult interface detailing, reducing the chance for error and hence costly remedial works.

The coupling of digitally controlled process with solid modelling techniques will mean greater design freedom at no extra cost.

(Buswell, Soar, Gibb, & Thorpe, 2007)

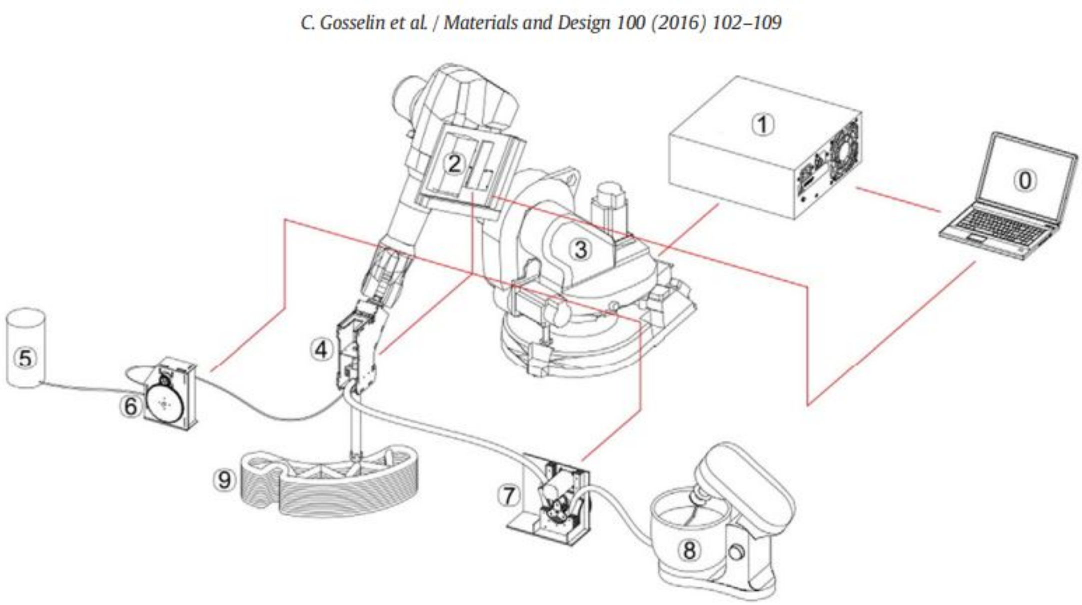
3.2.1 Ultra-high performance concrete

Geometric complexity enables multifunctionality and multiscale architecturation.

It is based on a FDM-like technique.

This process allows the production of 3D large-scale complex geometries, without the use of temporary supports. It reconciliates non-standard shapes, and low costs.

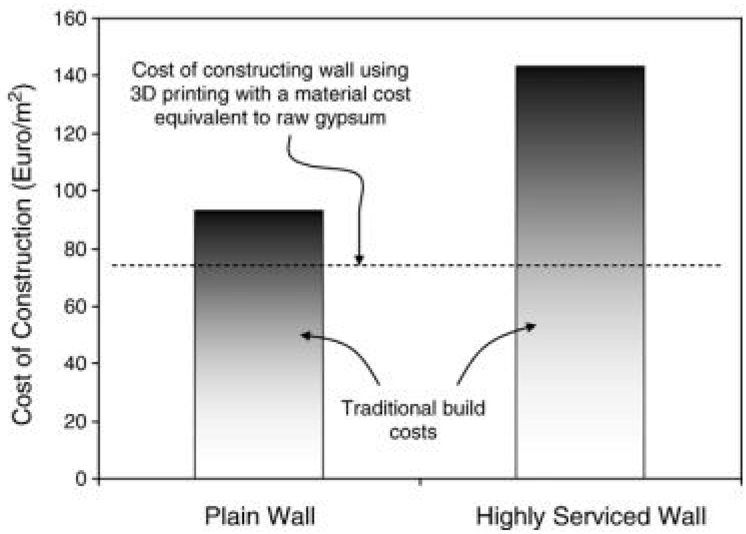
Multi-functionality was enabled for both structural elements by taking advantage of the complex geometry which can be achieved using this technology for large-scale additive manufacturing. This element was designed within a context of structural rehabilitation.



(Gosselin et al., 2016)

3.2.2 Cost

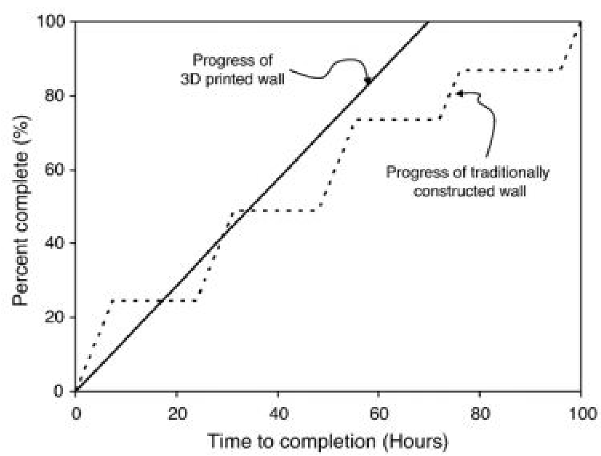
The cost of the wall using current 3D printing technology would be prohibitively expensive. However, we expect prices to become lower in time. If the price of the materials become low to the point to be on a par with materials used in traditional manufacturing, the prices of manufacturing complex geometries would be reduced greatly as shown in the picture.



(Buswell et al., 2007)

3.2.3 Time

Time wouldn't be improved significantly compared to traditional manufacturing. (The steps in the traditional methods come from having to leave every ~ 1 m height in brickwork overnight for the mortar to cure (maximum weight on wet mortar).)



(Buswell et al., 2007)

3.3 Use of 3D printing in the industry

In this section we will see some of the uses of additive manufacturing in construction. The examples selected are real structures built by Branch Technology, XtreeE, WASP and Winsun.

3.3.0.1 Branch Technology

3DP is being utilized on a larger scale is for the prefabrication of full scale building components such as interior walls and partitions.

They are using their patented “Cellular Fabrication” (C-Fab) method to prefabricate interior walls and partitions.

They have created an algorithm that generates a strong, yet lightweight geometric matrix made of ABS plastic and carbon fiber.

C-Fab Wall Partitions

(Kidwell, 2017)

3.3.0.2 XtreeE

They specialize in concrete printing.

The drains that are shown in the picture are supposed to be printed and finished in 9 hours.

3D concrete printed storm drain

(Kidwell, 2017)

3.3.0.3 World Advanced Savings Project (WASP)

They have a more eco-friendly approach to the topic.

This company has been experimenting with mixtures consisting of locally sourced clay, straw, lime, and sand to produce simple cylindrical shelters.

WASP 3D Shelter

(Kidwell, 2017)

3.3.0.4 Winsun

They create in 2013 10 small full-size prefabricated homes in just one day.

Each home measured $20m^2$, and cost \$4,800 to build. (50% of the material used were sourced from recycled construction waste).

Each wall is printed in a hollow fashion with an internal diagonal zig-zagging reinforcement system. This allows for the architects to implement calculated paths for insulation, plumbing, and electrical within their computer aided designs (Alter, 2016) treehuger.

Internal reinforcement and 3D printed house

Three years later, Winsun used the same printer and material to produce the worlds' first 3DP office building for the United Arab Emirates National Committee.

The total project duration from beginning of printing to finished assembly took only 17 days for a total of \$140,000 in construction and labor costs. (The building is around $250m^2$).

3D printed office

(Kidwell, 2017)

4 Aerospace Industry

In aerospace, really specific tools and components are used and the volume of production is really low. This characteristics are perfect in order to use 3D printing.

4.1 Prototyping

It's possible to create rapid prototyping for this industry, but 3D printing is more focused in final-use parts.

4.2 Manufacturing

Intelligent lightweight structures manufactured using laser sintering processes combine high strength with a weight reduction of 40–60%. The material savings translate into more flexibility in design and engineering. As a result, airplanes consume significantly less fuel and emit less carbon dioxide. (EOS, 2018 (accessed March 28, 2018))

The technologies used in this industry are:

- Fused Deposition Modeling (FDM).
- Selective Laser Sintering (SLS).
- Selective Laser Melting (SLM).
- Electron Beam Melting (EBM).
- Wire and Arc Additive Manufacturing (WAAM).

(Joshi & Sheikh, 2015)

4.2.1 Materials

Ti and Ni based alloys: Textile properties, damage tolerance, corrosion/oxidation resistance.

One of the major barriers to 3D printing is structural performance.

(Joshi & Sheikh, 2015)

4.3 Use of 3D printing in the industry

NASA's human-supporting rover has around 70 FDM parts and Airbus aircraft A350 XWB that has more than 1000 FDM parts. (Javelin, 2018 (accessed March 28, 2018)), (Hiemenz, 2016) and (Schwartz, 2018 (accessed March 28, 2018)).

Mars rovers & A350 XWB

Other use in this field is rapid tooling. Producing tooling directly from CAD models is regarded as an important method of reducing the cost and time to market for new products (Rosochowski & Matuszak, 2000). This is critical in an industry with high specialization as this one.

ACS helicopter fin (center) with a 3D printed drill guide (front).

(Hiemenz, 2016)

5 Automotive Industry

The use of 3D printing in this industry is focused on prototyping because of the price of the final-end parts. Companies with low volume are starting to use it and the customization will play a main role in this field.

5.1 Prototyping

At first, a 3D model of our product is done. It doesn't need to be accurate, we just need a base to work.

With that model 3D printed, the team can try to use it and see the improvements.

The improvements can be implemented manually directly on the 3D printed model.

At last, you can scan your model with the implemented improvements, optimize it with digital tools and print it again.

This process helps the design team to try and optimize the product to the fullest. It has help to decrease prototyping design time and cost, enabling them to experiment with plenty of different designs.

(Bizri, 2017 (accessed March 28, 2018))

5.2 Manufacturing

This technology is used to create specific pieces or tools, but it is struggling with fully print a car because of the aluminium alloy that it is used in the industry.

5.2.1 High-end cars

AM technologies allow F1 teams to build parts faster, stronger and lighter. This is because with this technology a F1 team can create a parts on demand.

These race-ready parts take days and vast amounts of money to produce, with 3D printing, they are ready within hours.

The Lamborghini Aventador has 3D printed parts that with traditional manufacturing would have cost $40,000 and 120 days while with 3D printing has cost $3,000 and 20 days.

Total freedom in the design pattern. It can be as intricate as the designer could imagine.

5.2.2 Fully 3D printed cars

LM3D by Local Motors is considered the first 3D printed car.

It is made up of 80% ABS plastic and 20% Carbon Fiber. The plastic is reinforced with carbon fiber, which applies to the chassis/frame, exterior body, and some interior features.

The mechanical components such as the battery, motors, wiring, and suspension, are all sourced from Renault's Twizy.

The LM3D cost about $53.000 and it should be completely road legal.

(Bizri, 2017 (accessed March 28, 2018))

(McCue, 2015 (accessed March 28, 2018))

5.2.3 Customization

3D printing allows you as a manufacturer to create different components at same cost. This means that it will cost you the same to create some intricate piece than a plain one once the design is finished.

Customization attracts a lot of money and with 3D printing, products can be fully customizable.

5.3 Use of 3D printing in the industry

This are a very specific examples of how has 3D printing help the design team to reduce price and time to market.

5.3.1 Formula Student Germany

They needed to design and build a reliable, lightweight axle-pivot (knuckle) with high rigidity, in the shortest possible time.

The knuckle needed withstand the dynamic loads that racing cars are subjected to while also reducing the overall weight of the car.

By optimizing the geometry of the knuckle the final design was 35% lighter than the original design and improved rigidity by 20%.

The use of AM technology also resulted in a significant reduction in development and production time and better reliability on the track (which in turn improved safety).

(Artley, 2018)

5.3.2 Eventuri Company

The company manufactures high-performance carbon fiber air intake ductwork for a range of high-end models, including the BMW M-Power and Audi RS ranges.

They use 3D printing to test the CAD models before manufacturing them in carbon fiber due to the costly mold-making process.

(Keane, 2017)

5.3.3 Volkswagen Autoeuropa

Volkswagen is using 3D for rapid tooling.

When a new model of a particular car hits the market, the components of the car change from the previous version, as do to the workflow and associated tools.

Currently, 93 percent of tools that were previously outsourced for manufacture are made at the Volkswagen Autoeuropa plant, allowing for a 91 percent reduction in tool development costs and a 95 percent reduction in tool lead times.

In 2016, the plant saved €150.000, and that figure has been predicted to rise to €325.000 for 2017.

(Keane, 2017)

5.3.4 Tucci Hot Rods customization company

They use 3D printing to end-use parts.

Tucci Hot Rods has tripled the speed at which these parts are produced, while reducing the cost of manufacture by a whopping 90 percent.

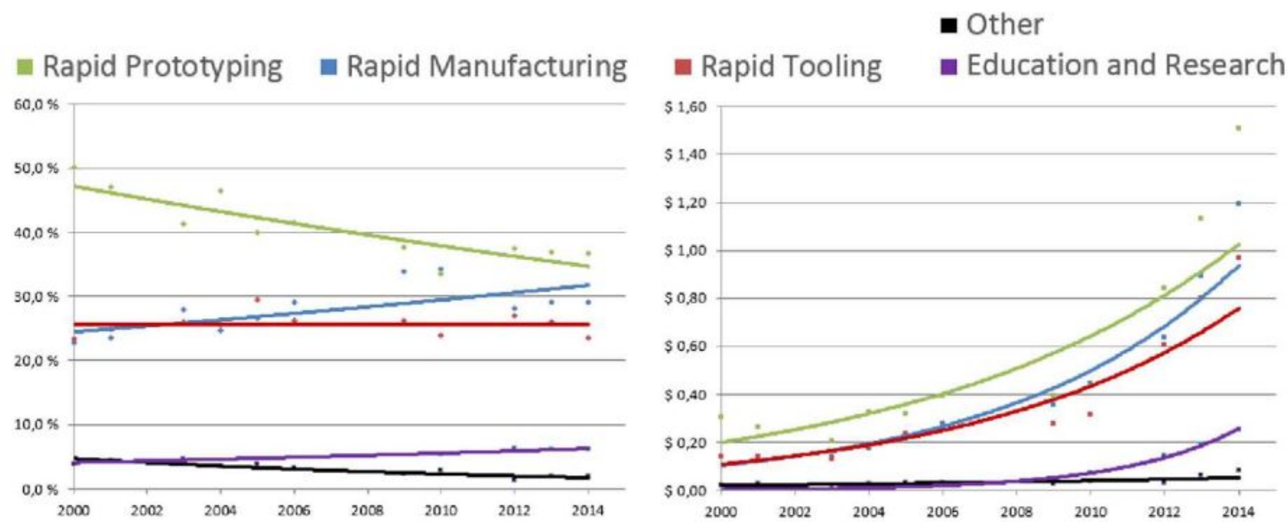
A custom job like the shown in the photo would have taken between six and 12 months while with 3D manufacturing the entire car was finished in just two months.

In terms of cost, Tucci Hot Rods estimate that an average of $500 is saved per part, compared to its previous traditional machining methods.

(Keane, 2017)

6 Novel Materials

3D printers have become inexpensive enough to be used by individuals and smaller businesses.



Percentage of usage of the technology per application and revenue in US$ billion per industrial application(Source: Wohlers, 2014 adapted in TEKES, 2015 - Teknologian Kehittämiskeskus [the Finnish Funding Agency for Technology and Innovation]).

(Kapetaniou, Rieple, Pilkington, Frandsen, & Pisano, 2018)

6.1 Digital materials

A digital material is an advanced composite material that consists of two or three photopolymers in specific microstructures and ratios.

It can be used to create a functional prototype with tunable characteristics, such as superficial hardness, colors and textures.

Digital materials can simulate various elastomers, mimic standard plastics, produces photorealistic details for different kind of applications, such as functional prototyping, manufacturing tooling, medical models and communication models.

(Lee, An, & Chua, 2017)

6.2 Smart Materials for 4D printing

Smart materials are defined as those materials have the capability to transform their geometry under the influence of external stimuli.

4D printing is an emerging topic in the field of 3D printing, where the fourth dimension is time and the basic concept of 4D printing is based on the 3D printing of programmable smart materials that can gradually change the shape over time under external stimuli, such as water and heat.

(Composite hydrogel architectures that are programmed with anisotropic swelling behavior controlled by the alignment of cellulose fibrils along prescribed four-dimensional pathways).

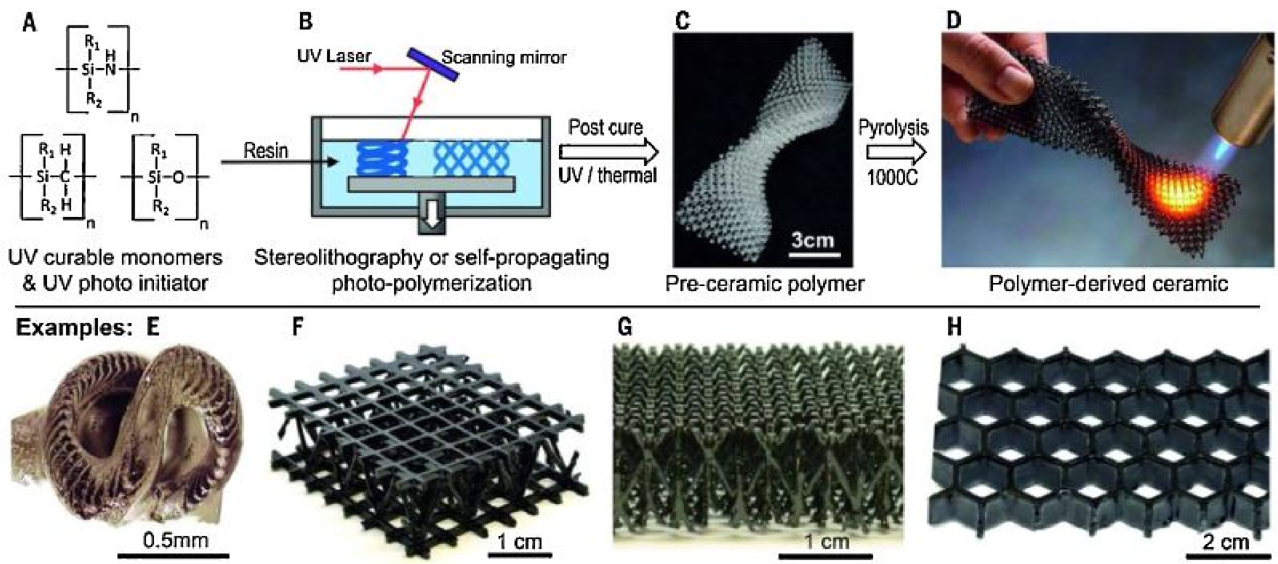
(Lee et al., 2017)

6.3 Ceramic Materials

Current AM methods can produce ceramics parts without any cracks or large pores through optimization of the parameters of AM process and their mechanical properties are similar to those of traditionally fabricated ceramics parts.

The 3D printed ceramics parts showed excellent thermal stability after pyrolysis at one thousand degree Celsius and almost no shrinkage was observed.

These ceramics materials are of interest for thermal protection systems, propulsion components, electronic device packaging, microelectromechanical systems, porous burners.



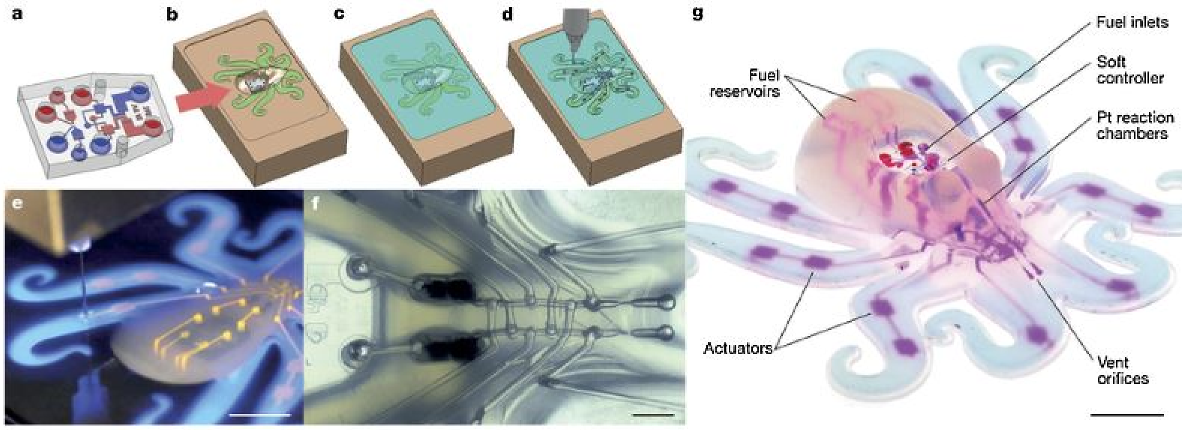
Additive manufacturing of polymer-derived ceramics.

(Lee et al., 2017)

6.4 Electronic Materials

Current AM technologies allow fabrication of functional electronics, such as antenna, capacitors, resistors and inductors, in a single step without any post-processing.

With the advent of 3D printing, it is possible to fabricate soft robots, which is composed of soft materials and without any electronic components using multi-material embedded 3D printing technique (EMB3D).

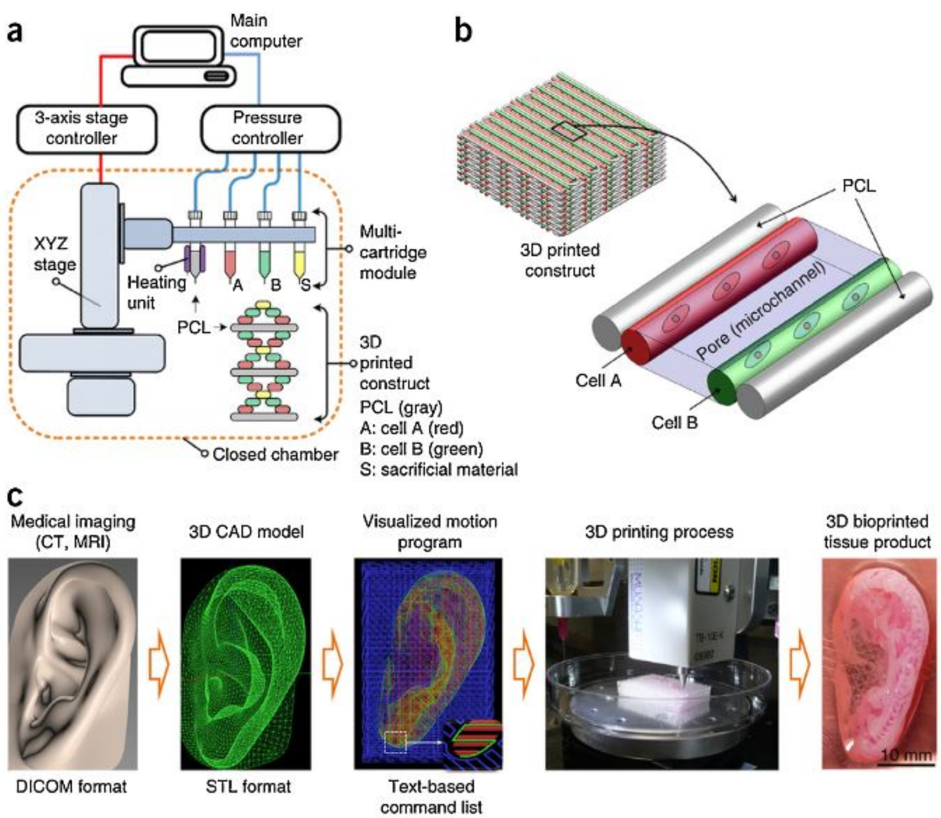


Fully soft, autonomous robot assembly.

(Lee et al., 2017)

6.5 Biomaterials

Recent developments in biocompatible materials have enabled 3D bio-printing of functional living tissues, which can be applied to regenerative medicine to address the need for organs transplantation.



Integrated tissue–organ printer (ITOP)system.

(Lee et al., 2017)

7 Conclusion

In construction industry, the usage of additive manufacturing still needs a lot of development. The technology is mature enough to print a full house (Kidwell, 2017) even with high quality concrete (Gosselin et al., 2016). However, the prices of this kind of constructions are not low enough in order to be competitive. As said before (Buswell et al., 2007), the price of the material used in 3D printing has to be similar to the one for raw gypsum (typical material use in traditional manufacturing) in order to be really profitable. If it becomes low enough, we will be able to build intricate structures at the same price as plain ones. It would mean a huge step in freedom when it comes to the design process. Nevertheless, the future of construction is most likely to be an integrated process that allows organisations to take advantage of both conventional and 3D printing technologies at the same time, as said in (Tay et al., 2017).

On the other hand, we have aerospace industry. In this industry, the main objective is to create light components able to resist high stresses. 3D printing has been able to aid reduction in weight through complex and net shape manufacturing with less number of joints and intricate geometry. This means a huge cut in costs. And therefore, has the potential to be the new manufacturing standard (Lyons, 2014). Also, in this industry we have a very low volume of production that makes pricing more than competitive comparing with traditional manufacturing. The disadvantage in this field is the need of high safety ratios. Testing and safety standards for AM in aerospace are still under development. (printing patterns, porosity built-up, and uneven print flow) (Hiemenz, 2016).

Automotive industry uses 3D printing for prototyping, rapid tooling and final-end components. Prototyping allows the design team to work significantly faster, and thus, cheaper (Artley, 2018). In addition, they are able to test their components before manufacturing them in a more expensive material such as carbon fiber. Each year, a car company can produce different models of cars. Being able to create specific tools for each one can grant the company to save a significant amount of money (Keane, 2017). There are cases of fully printed cars, but technology is not ready yet. This is due to the fact that automotive industry uses aluminium alloys difficult to work with in 3D printers. An important field in this industry is the customization, and as we mentioned earlier, the use of 3D printing allows us to fabricate different designs at the same price. Once the technology is cheap enough, the fully customization of a car without additional cost will be possible.

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