Experimental Prototype Design for EXPO2020

A Sustainable Approach in Additive Manufacturing

With recycled material

By: Sara Hajifathaliha

Master of Science in Architectural Engineering,
Polytechnic University of Milan

Thesis advisors:
Prof. Ingrid Paoletti

Acknowledgement:

To the love of my life, My husband, his love and encouragement gave me the strength and motivation, to complete this project and overcome all the obstacles, during my Master's degree.

To my Professor, Ingrid Paoletti, for her academic assistance, support and dedication from the beginning of the process which pushed me to realize the vision and provided me the necessary contacts and materials.

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Preference

3D printing is a term to describe technology used for the rapid production of 3D objects directly from digital computer aided design (CAD) files. Today, 3D printers can process a wide variety of materials and produce fully functional components. 3D printing technologies have been explored for a wide range of applications including robotics, automobile components, firearms, medicine, space, etc. With the advancement of both materials and 3D printing hardware, extremely expensive components can be produced in higher speed and lower cost, It is expected that 3D printing could transform the economy, with an impact of up to $550 billion a year by 2025 The 3D printers found on most college campuses, as well as those seeing the highest consumer demand, are FDM printers, which utilize a spool of plastic filament as the source material for the 3D printing process.

This consumable plastic filament must be replaced, much like the ink in a standard ink-jet printer, at a cost approaching 30-40 euro per spool. Currently printer filament is typically produced using a traditional extrusion process. While commercial printing filaments are usually polymers, such as polylactic acid (PLA) or acrylonitrile butadiene styrene (ABS), Polyethylene Terephthalate (PET), There are a lot of advantages in using plastic in 3D printing. These advantages are particularly valuable for research apparatus and specialist equipment for which new designs must be tested, for example, in biomedical applications. 3D printing allows for more complex designs to be created than when compared to more conventional manufacturing, besides, Plastics are inexpensive, require little energy to manufacture, and are biocompatible and lightweight. This makes them an ideal material for single-use disposable devices.

Most water bottles and other containers that are labeled with the number 1 recyclable symbol are made from the plastic PET. PET is created by the polymerization of ethylene glycol and terephthalic acid and it is used to manufacture a variety of products. PET's transparency, high impact resilience, ability to create a barrier from gas and moisture, shatter resistance, and resilience to solvents are the characteristics that make PET desirable for manufacturing.

Although PET is a desirable material when it comes to manufacturing containers, PET is not a popular source material for 3D printing. When it comes to 3D printing, a modified version of PET is commonly used. Glycol is added to the material composition during the polymerization process of PET to create PETG. This allows for the manufacturing of a higher quality of filament when compared to PET. Although the acronyms look similar, the addition of the added glycol essentially creates a whole new plastic. The resulting filament is more transparent, less brittle and easier to use than the base form of PET.

This Thesis explores the emerging challenges and opportunities of using Recycled material in AM technology for a more sustainable Architecture, ranging from new developments of materials in terms of usability to design opportunities and informative applications. The first chapter of this thesis study a mathematical theory called circle-packing as a challenge for the design and construction parts, first chapter focuses of packing circles, proof mathematically the theory and indicates computational scripts and case studies, the second chapter outlines various types of additive manufacturing and the revolutionary influence of AM in supply chain and product manufacturing. Chapter three investigates the technology of recycling plastic and adopting it in AM technologies, an analytical framework describes material behavior comparing recycled filament and virgin filament of PLA, PET and PETG material, recycled PETG has got the best results in terms of thermal and mechanical behavior. The framework allows a better understanding of potentials and weaknesses that recycled material offers compared to virgin filaments.

The final Chapter in this thesis is the experimental Design part with AM technology, a modular design which is inspired by circularity of the Logo of Expo 2020, will be practically studied to be bulilt with three different types of 3D-Printers: 0.7mm and 1.2 mm nozzle size WASP 3d-printer, and 3 mm nozzle size Delta 3MT WASP 3Dprinter, and also with using many different filaments and pellets mainly recycled PETEG filament provided by Filo alfa. In this chapter it will be shown that how the design has the ability to be printed, packed, transported and assembled and installed in the site by a very simplicity of junctions and portability is the main challenge in this design prototype, the result of the modeling will indicate and prove the feasibility of the design with Sustainable approach for using 3D Printing technology with Recycled Materials and future developments will be expected with these kinds of practical experiments.

CHAPTER 1

Tangent Circles on the plane using Varaible Compass

The present Project analyzes how to trace tangent circles, using geometric rules in mathematics and how to develop a pattern, using circle packing idea, In geometry, circle packing is the study of the arrangement of circles (of equal or varying sizes) on a given surface such that no overlapping occurs and so that all circles touch one another, this method has been used by artisans to make ornamental pattern in architecture and arts, The present Chapter will demonstrate on how to develop a pattern of circle-packing and how to attain to tangent circles repeatedly.

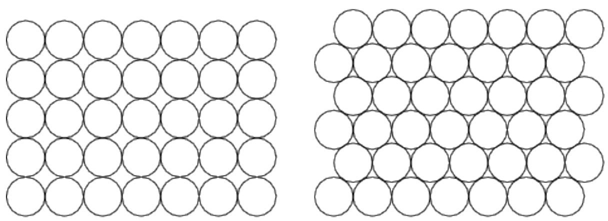
Key-words: Circle packing, Tangency, Circumcenter, Centroid, Tessellation, Architectural Geometry, incircle, inscribed circle.

Introduction

In the present study, the same idea is developed, but the tools used are a ruler and a variable compass, which implies that different geometric constructions using circles with several diameters can be made. This chapter focuses on keeping regularity as much as possible when making more complex geometric constructions, especially on how to get different circle packings contained within a circle, such as rosettes and rose windows, which have been used extensively in architecture throughout history.

What is circle packing

In Geometry circle packing is an arrangement of circles inside a given boundary such that no two overlaps and some (or all) of them are mutually tangent. The generalization to spheres is called a sphere packing. Tessellations of regular polygons correspond to particular circle packings.
In geometry, tangent circles (also known as kissing circles) are circles in a common plane that intersect in a single point. There are two types of tangency: internal and external.



square packing *hexagonal packing*

Tangent Circles between Secant Straight Lines

Here we define 2 exact geometric ways tracing tangent circles between secant lines: First, with a given circle with Center O on a Straight-Line r, a tangent to the circle can be drawn from Point P on the same reference line (Fig.1. 1), T is the inter section between the circle centered at the midpoint of Distance OP, and the initial circle with a center at O. The OTP triangle formed will have a right angle at T (The opposite side of the arc is half of the Arc and here the arc is 180), and the PT line will therefore be tangential to the initial circle. We then extend the Line to cut the initial circle, and Point H is achieved. From Point H, a straight line to Point A is traced (the cutting point between Baseline OP and the initial circle), and then we extend this line to cut the Tangent Line TP, to obtain Point B. Trace a parallel line from Point B to Line TH, and cut Line OP at O0, then we trace a circle with center (O0); with Radius BO0 or AO0, which is tangent to the initial circle and tangent to TP. By a recurrent procedure tangent circles between secant straight lines from an initial given circle and a given point where straight lines intersect, is achieved in this way.

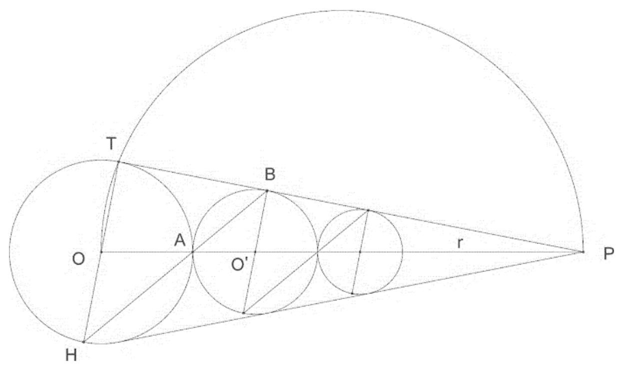


Fig .1. 1 Tangent circles between secant lines solved by Archimedes

The second way to draw tangent circles between secant lines is by drawing bisectors, by taking two secant straight lines (r, r’) that have an intersecting point at P, we draw an arc with the center at P, cutting Lines r and r’ at Points T and T’ (Fig.1. 2). Then we draw Line TT’ and then trace a perpendicular from P, cutting Line TT’ at its midpoint (H), From Point T, trace the bisector of angle HTP by means of a fixed compass. The bisecting line cuts Line PH at O, which is the center of the first desired or initial circle where OH is the radius. To obtain the next circle, trace a parallel line to Line TT’, touching point H’ (cutting the point between Line PH and the initial circle with a center at O), or another way of doing this would be by tracing an arc with a center at P and Radius PH’, producing a line parallel to Line TT0, which is closer and easier to move to Point H’. Once this parallel line touching H’ is obtained, this geometric construction can be repeated to obtain bisecting lines (obviously parallel to Line TO) and, therefore, obtaining the next desired center (O’), its radius being O’H‘, and so on. This procedure is recurrent. Fig.1. 3 can be a very simple example of a simple rotation.

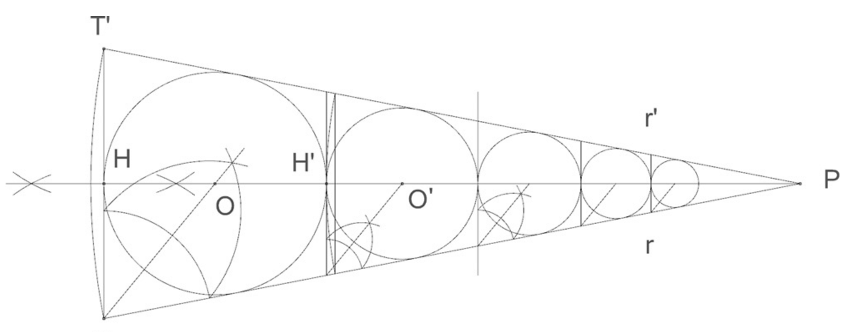


Fig.1. 2 Tangent circles between secant lines can be resolved by drawing bisectors

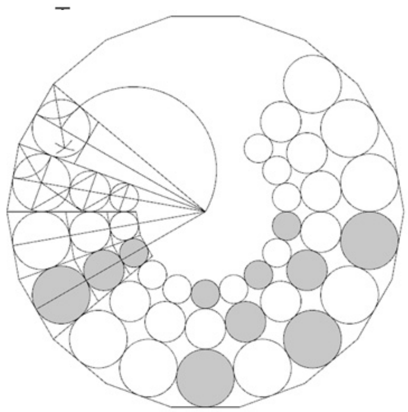


Fig.1. 3 How to make radial circle packing by applying the bisector method in Fig.1. 2

Layout of Rose Window in Abbey Church of Saint Alban (England)

Here is a case study to see how architects and other craftsmen have been worried throughout history about how to get a circle packing within a circle with variable diameters, it is the rose window in the Abbey Church of Saint Alban (Abbey Church 2016). The rose window is based on the number 9 to divide the circle. Division by 9 has no accurate Euclidian solution because it implies division of the angle into three parts, one of the classic problems without solution in the geometry of ruler and compass. However, craftsmen and architects have used approximate solutions throughout history. The layout can be started by drawing from the interior to the exterior (drawing a nine-circle chain), or vice versa (starting from an 18-circle chain). In this case, it is begun from an exterior 18-circle chain, as is shown in Fig. 11(a), dividing the circle into 18 sectors. By means of bisectors, draw one circle inscribed (c1) into each of 18 sectors (OAB). The next step is to draw a circle inscribed into sector (OAC) and make it tangent to the two contiguous circles of the first chain [Fig. 11(b)]. In this way, Circle c2 is generated, and rotating it 9 times gives rise to the nine-circle chain [Fig. 11(c)]. To produce the last circle chain, draw a circle (c3), which will be tangent to the two circles of the last chain, as well as tangent to the Radius OD [Fig. 11(c)]. Rotating circle C3 will produce the interior nine-circle chain, and only drawing the central oculus remains [Fig. 11(d)]. This layout can be overlapped onto a picture of this rose window.

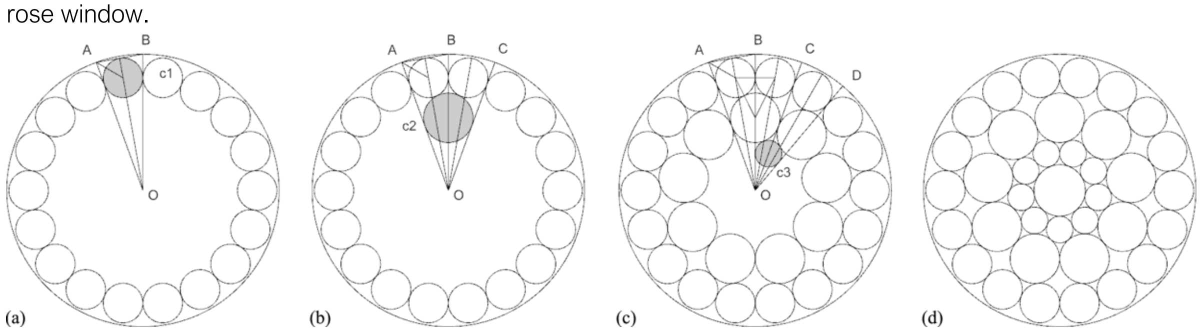


Fig.1. 4 Analysis of layout of rose window in Abbey Church of Saint Alban (England): tracings for obtaining (a) first circle ring, (b) second circle ring, and (c) third circle ring; (d) definitive pattern

Mathematical Analysis of Alternate Circle Packing

Here is a more detailed analysis on geometric construction of alternate circle. We start drawing a tangent circle ring using the bisector procedure, as shown earlier in Fig.1. 2 : we trace a bisecting line between Radius OA and Side AB, which will cut the sector's apothem at C1 Fig.1.4 In this way, trace the first circle (c1) centered at C1 with Radius DC1, perpendicular from C1 to AO. In this case, Archimedes' construction is used to create the second circle chain. Hence, all circles are lined up into the circle sector OAB, creating a second inner circle (c2). Draw a parallel line to CD touching Circle Center c2, passing by G, and cutting Circle c2 at Point H. Extend this straight line to cut Radius OB at I and join this point with Point C1—center of Circle c1—cutting c1 at J, which is the desired tangent point between both Circles c1 and c2.
As previously shown in Fig.1. 5, the first circle (c1) is obtained by means of bisectors. From Point O, trace an arc touching the C1 center to cut Line OB at Point D. Making the center at Point D, trace a circle with the same radius as Circle c1, cutting Circle c1 at Point E. Then, trace a straight line from Point C1 passing by Point E and cutting Radius OB at Point C2. With the center at C2, trace a circle (c2) whose radius is perpendicular to the distance from C2 to Apothem OC1 at P2, which is the same distance as EC2. The

geometrical construction shown in Fig. 12(c) summarizes the right construction that is used to repeat the procedure, as shown in Fig.1. 5. By joining successive centers (C1, C2…, Cn), a polygonal line is drawn following an asymptote curve up to O, the rosette's center. For each angle (a/2, corresponding to half-angle of a regular polygon dividing the rosette circumference), there is an angle (w) that leads the asymptote curve, marking a constant course with the rosette radius. This steady course, when traced in a sphere, is a loxodrome, which is the course that navigators follow using the ship's compass.

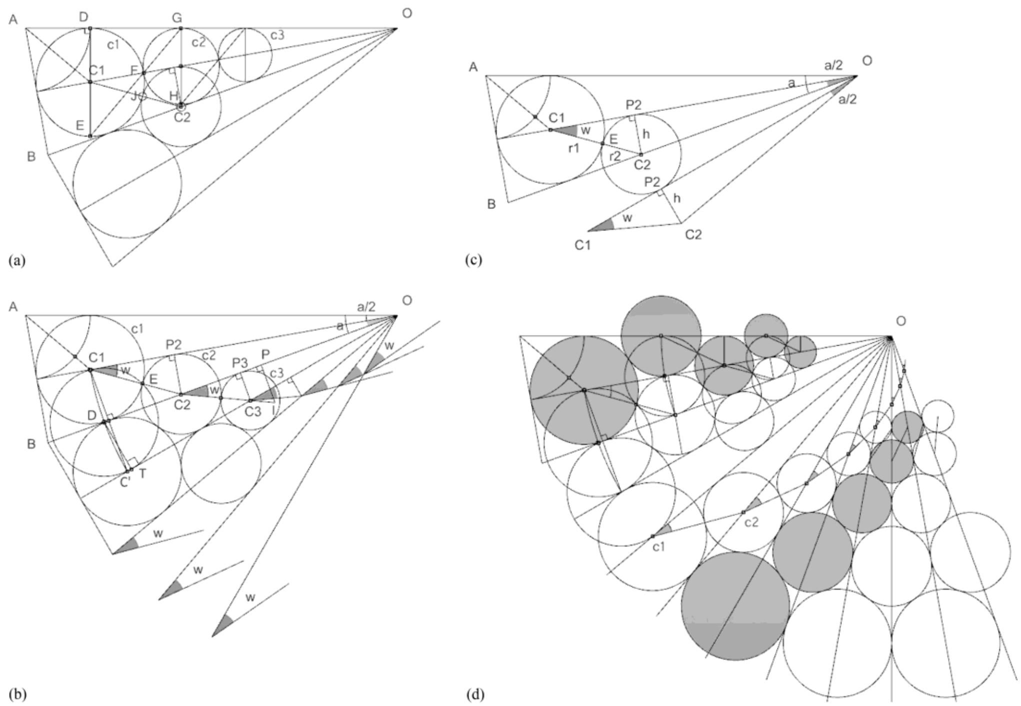


Fig.1. 5 Analysis of alternate circle packing: (a) how to obtain the C2 circle center from a first circle ring; (b) how to obtain the next C3 circle center of the third ring; (c) detail of keeping the w angle; (d) relation between alternate circles and the sequence of alternate circles

Packing circles and spheres on surfaces

Up to now we have studied the circle packing arrangements on the plane, but this question arises that how we can extend these results to surfaces. We must study triangle meshes to answer this question, where the incircles of the triangles form a packing, i.e., the incircles of two triangles with a common edge have the same contact point on that edge (Fig.1. 6 and Fig.1. 7) In geometry, a sphere packing is an arrangement of non-overlapping spheres within a containing space. The spheres considered are usually all of identical size, and the space is usually three-dimensional Euclidean space. However, sphere packing problems can be generalised to consider unequal spheres, n-dimensional Euclidean space (where the problem becomes circle packing in two dimensions, or hypersphere packing in higher dimensions) or to non-Euclidean spaces such as hyperbolic space.

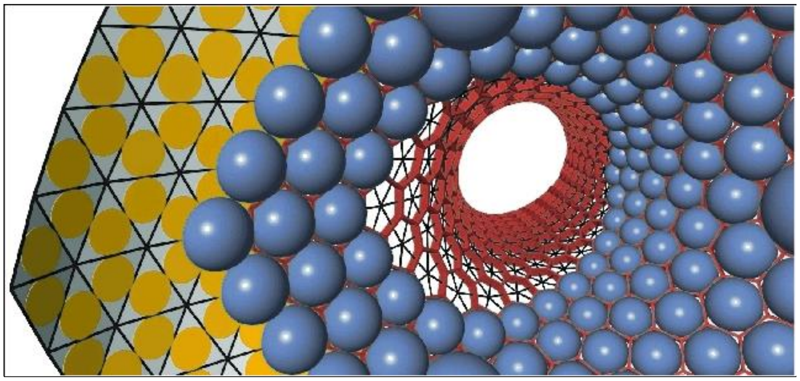


Fig.1. 6: A CP mesh is a triangle mesh whose incircles (orange) form a packing. Then spheres (blue), which are centered at mesh vertices and are orthogonal to the incircles of neighboring triangles form a packing, too. Centers and axes of incircles define a hexagonal support structure with torsion-free nodes.

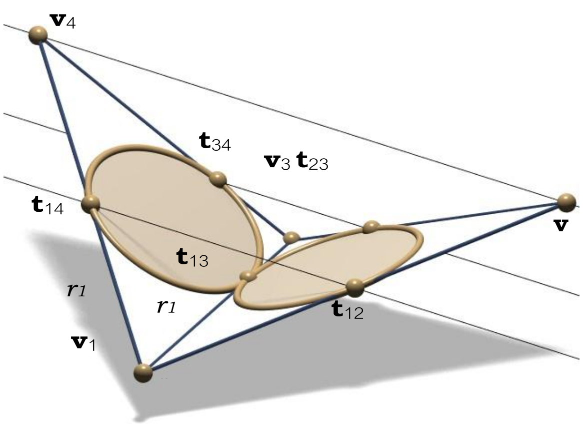


Fig.1. 7: We have introduce notation for a pair of adjacent triangles in a CP mesh: Vertices v_j, points of tangency with incircles t_{ij} , distances $r_i = [v_i – t_{ij}]$. Note that t14, t12, t34, and t23 are co-planar.

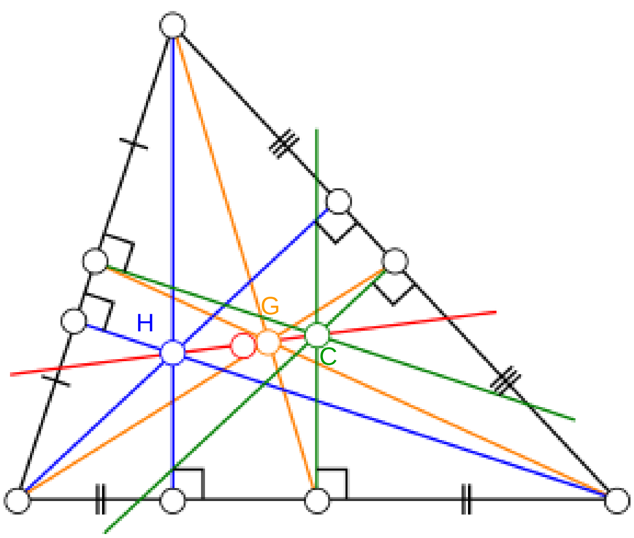


Fig.1. 8 Triangle Centers:

C: Circumcenter Point, the center of a triangle's circumcircle. It can be found as the intersection of the perpendicular bisectors.

G: Centroid, the intersection of the three medians of the triangle (each median connecting a vertex with the midpoint of the opposite side).

H: Orthocenter, the point where the three altitudes of a triangle intersect. An altitude is a perpendicular from a vertex to its opposite side.

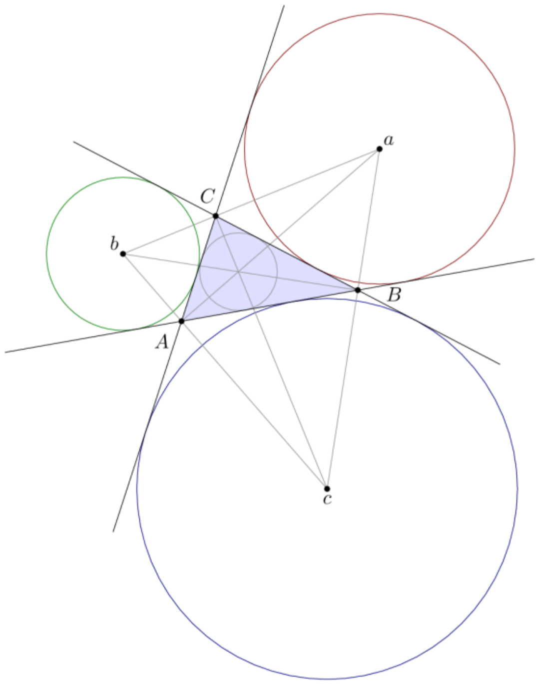
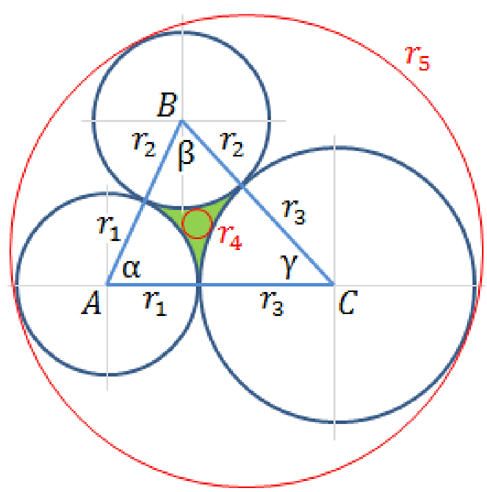


Fig.1. 9 In geometry, the incircle or inscribed circle of a triangle is the largest circle contained in the triangle; it touches (is tangent to) the three sides. The center of the incircle is a triangle center called the triangle's incenter. An excircle or escribed circle of the triangle is a circle lying outside the triangle, tangent to one of its sides and tangent to the extensions of the other two. Every triangle has three distinct excircles, each tangent to one of the triangle's sides.

Coding Circle Packing



To get the Area between three tangent circles, we define:

a = r2 + r3 b = r1 + r3 c = r1 + r2

The area of triangle ABC is:

$$A_T = \frac{1}{4}\sqrt{(a+b+c)(a+b-c)(a-b+c)(-a+b+c)}$$

The sectors area is:

$$A_A = \frac{\alpha}{2}{r_1}^2 \qquad A_B = \frac{\beta}{2}{r_2}^2 \qquad A_C = \frac{\gamma}{2}{r_3}^2$$

And the area between the 3 tangent circles (green area) is:

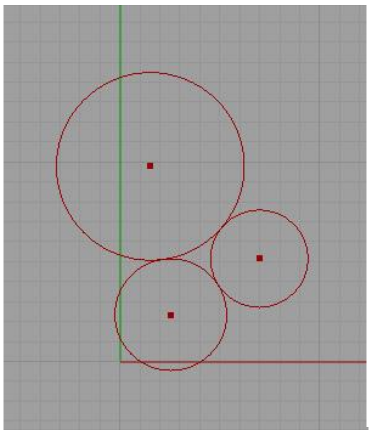
A = AT − AA − AB – AC

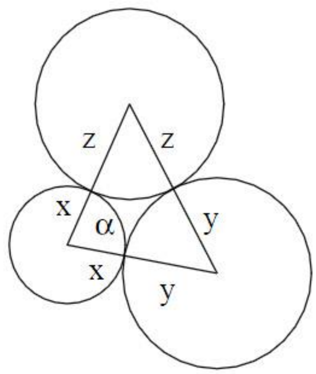
The angles of the triangle ABC can be found by cosine law

$$\alpha = \cos^{-1}\frac{b^2+c^2-a^2}{2bc} \qquad \beta = \cos^{-1}\frac{a^2+c^2-b^2}{2ac} \qquad \gamma = \cos^{-1}\frac{a^2+b^2-c^2}{2ab}$$

Computing:

Although we can find solution by using an evolutionary solver (Galapagos) or physical engine (Kangaroo) but there is there is a solid geometric solution other than an agent based optimization. For the result of a full packing, no pushing circles leaving gaps, we need to provide a method first. (Fig 1. 11) It might be much easier in a recursive scripting environment, but I am searching for a method to model a solution in particularly in Grasshopper3D.

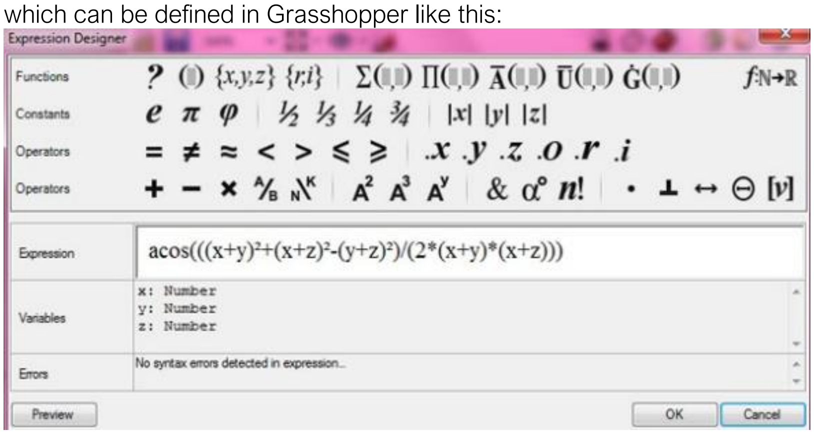




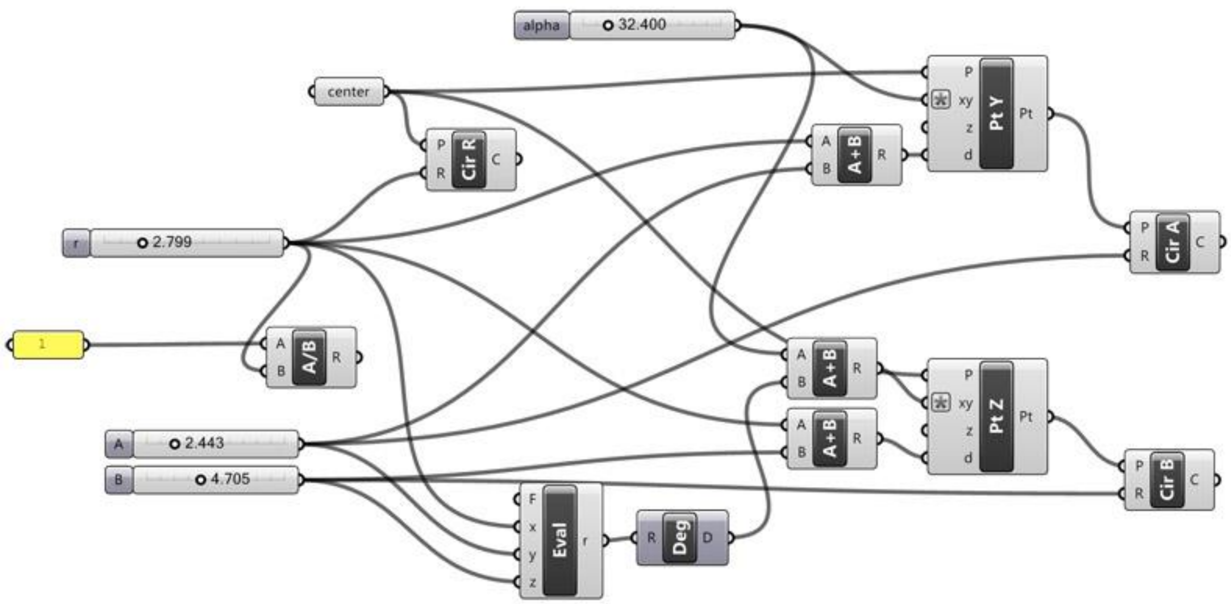
So far, we proved "three tangent circles" function and we will use it to create the circle that is tangent to two others easily and quickly. But there is a solid mathematical background about it. The angle alpha above can be computed with:

$$\alpha(x; y, z) = \arccos\left[\frac{(x+y)^2 + (x+z)^2 - (y+z)^2}{2(x+y)(x+z)}\right].$$

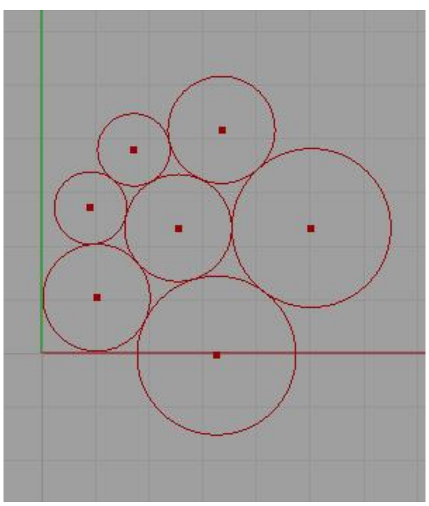
which can be defined in Grasshopper like this:

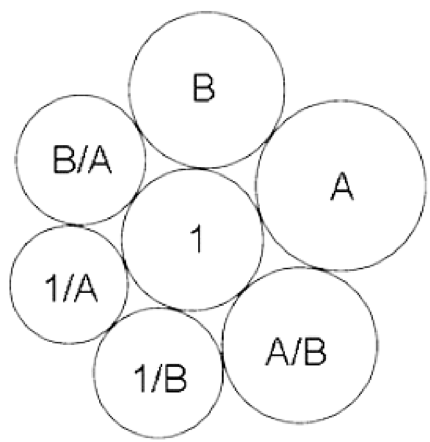


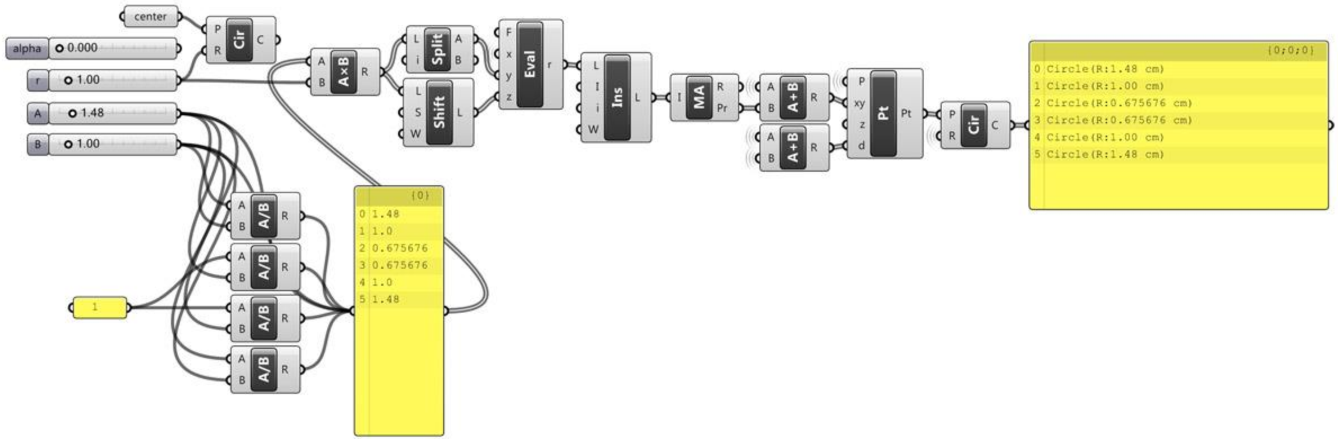
This way, we can create three tangent circles just by entering their radii. The rest is math;



Then, we can multiply this process to create one flower of a Doyle spiral, a famous rule that explains the relationships of 6 tangent circles' radii.



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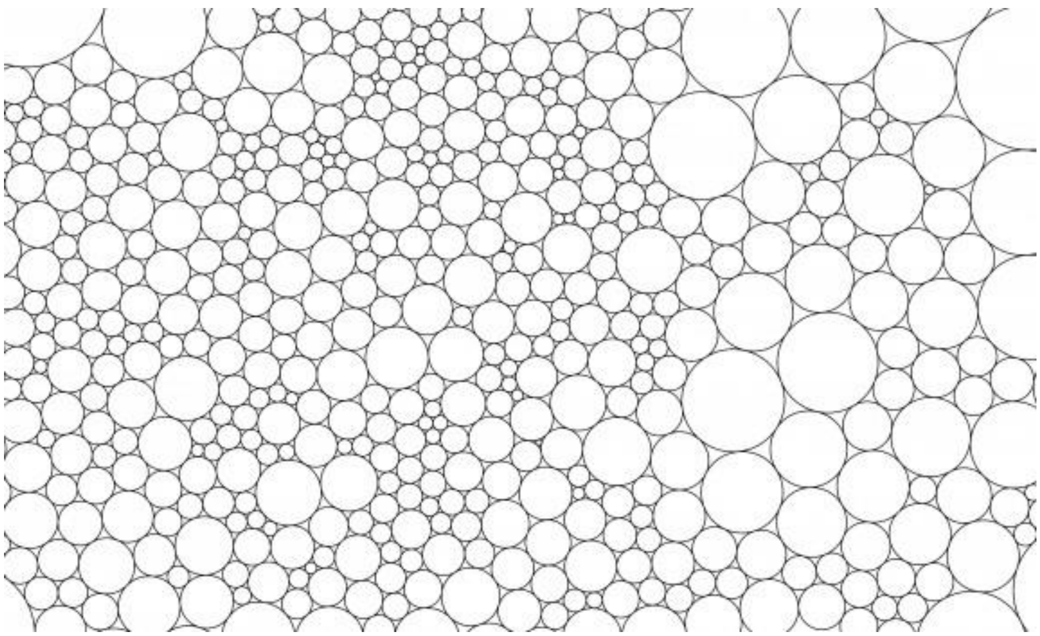
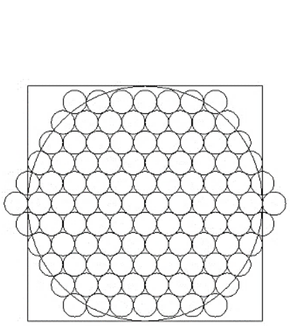
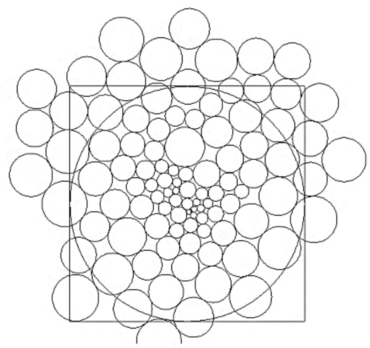
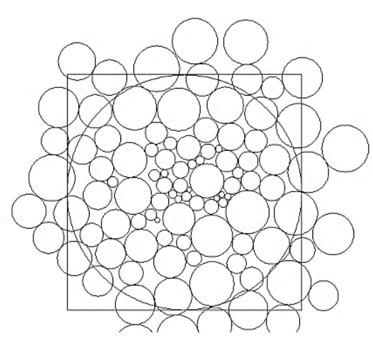








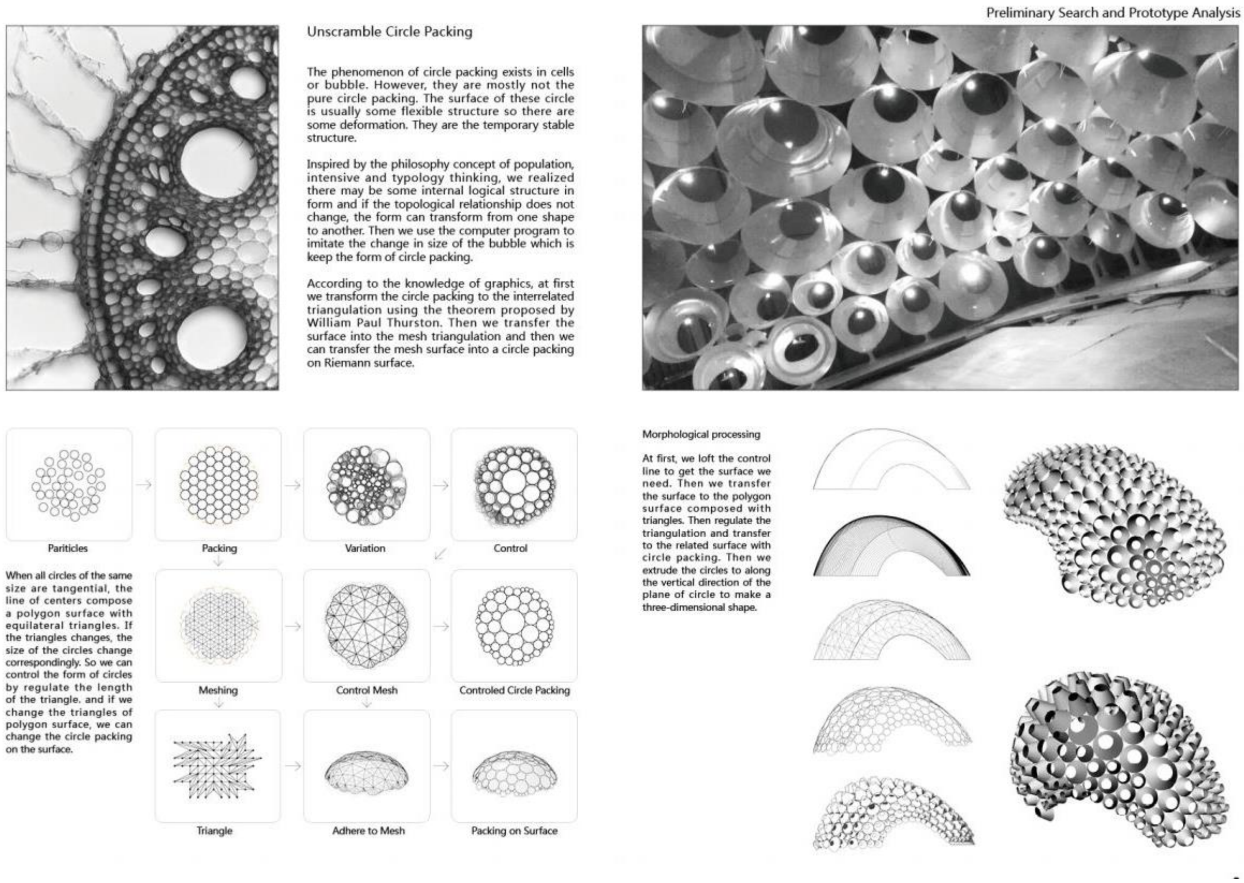
Conclusion:

To sum up; this chapter was an attempt to analyze the applications of circle packing in architectural layouts specifically the case study that was studied in Fig.1. 4, it began with trying to draw tangent circle chains inscribed in a circle. Archimedes provided a first demonstration and a first way to trace a sequence of tangent circles between secant straight lines. However, craftsmen could have used much simpler geometric construction by means of bisectors when they tried to draw an inscribed circle chain rosette.
The use of circle packing in ornamental patterns achieved a very important interest in the Gothic period, especially tracing rose windows. The first compositions began tracing a first inscribed circle chain, and then patterns grew in complexity. First, the rose window patterns used a sequence of aligned tangent circles. This technique will be used later in the process of design and it will be parametrized in grasshopper.

Circle packing as a discipline quickly attracted the interest of researchers in analysis, combinatorics, geometry, and topology, and initially developed along "two not disparate branches. The one branch may be characterized broadly as analytic and combinatorial in style with particular attention focused on the topic of Thurston's Purdue talk; namely, the relationship of circle packing to the approximation of conformal mappings. The other branch may be characterized broadly as geometric and topological in style with particular interest in the pure geometry of circle packing. The results are often beautiful and sometimes surprising.

Case studies used circle packing in Design:

1. Circle packing pavilion (an inspiration from nature)



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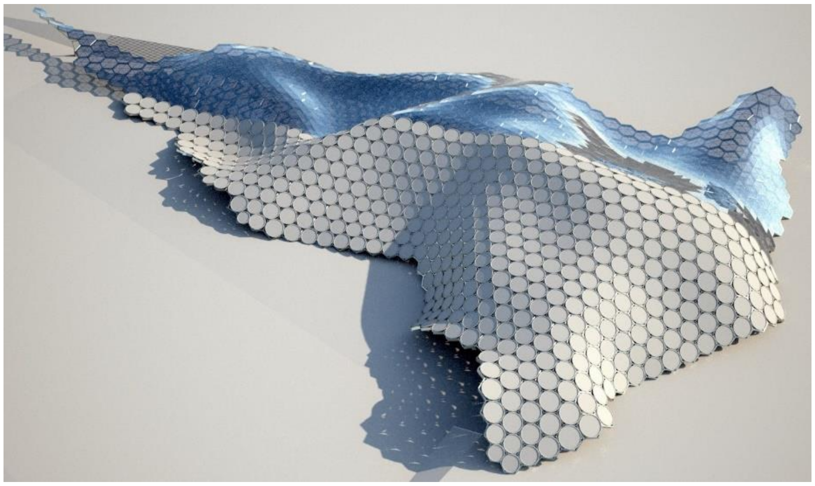
2. Resolving a freeform shape into circle-bearing hexagons. This is one of the many possible structures derived from a newly introduced type of triangle mesh, where the incircles of triangular faces form a packing. Such derived structures enjoy interesting properties relevant to both geometry and building construction.



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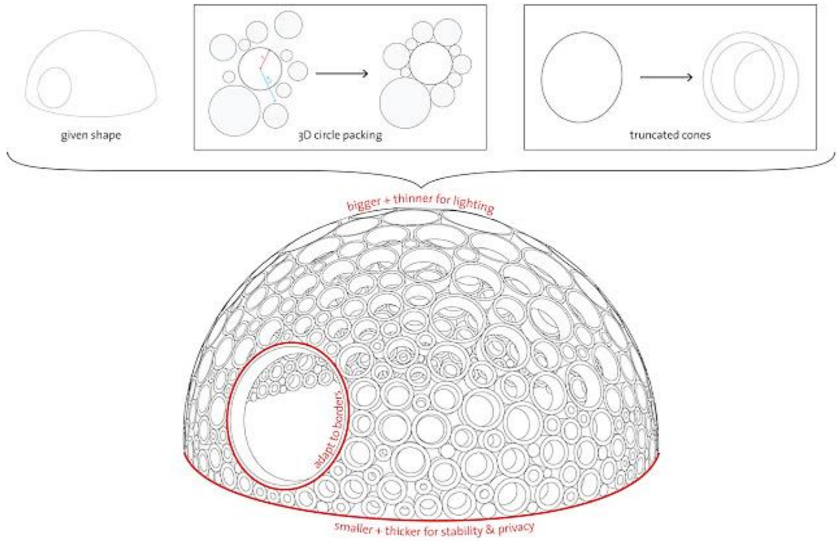
3.Packed Pavilion:

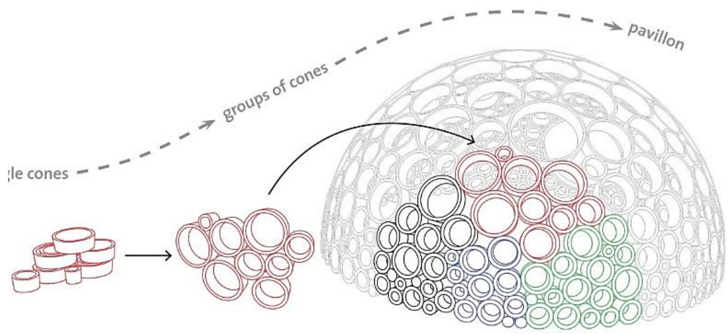
The pavilion features a bottom-up design composed of variable truncated cones, 409 in all, in which these basic constructive elements are filling the entire surface creating a network. The cones negotiate their parameters with each other by adapting their size, form and position. While maintaining their individual diversity and freedom, the elements cooperate to achieve common goals such as overall stability, shape, illumination, views and spatial quality.

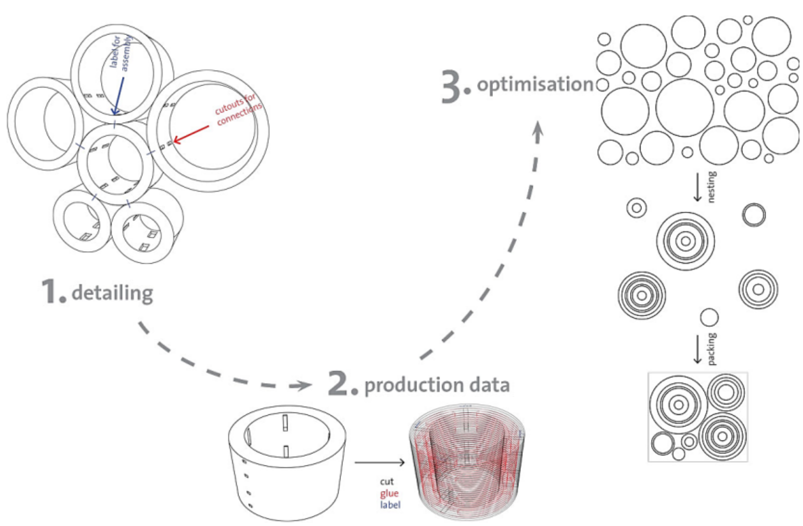
The cones were manufactured using corrugated cardboard in 28 layers, each of which was cut, glued and labelled with a computer-controlled machine. Weatherproofing is provided by a shrink foil, a packing material like all the other that are constituting the pavilion. For all steps, from design, production, logistics, packing in Zurich to shipping and assembly in Shanghai, the process was implemented and optimized by means of self-made computer programs. By intelligently nesting and packing the cones the amount of material used, the production time and the shipping volume were significantly reduced.

The experiment is intended to demonstrate how architects can use CAAD to customize a design process. It was possible on one side to overcome logistical and fabrication constraints with integrated solutions, and on the other side to exploit the potential of digital design on the aesthetical level.

Picture credits: http://packed-pavilion.blogspot.it/p/concept.html







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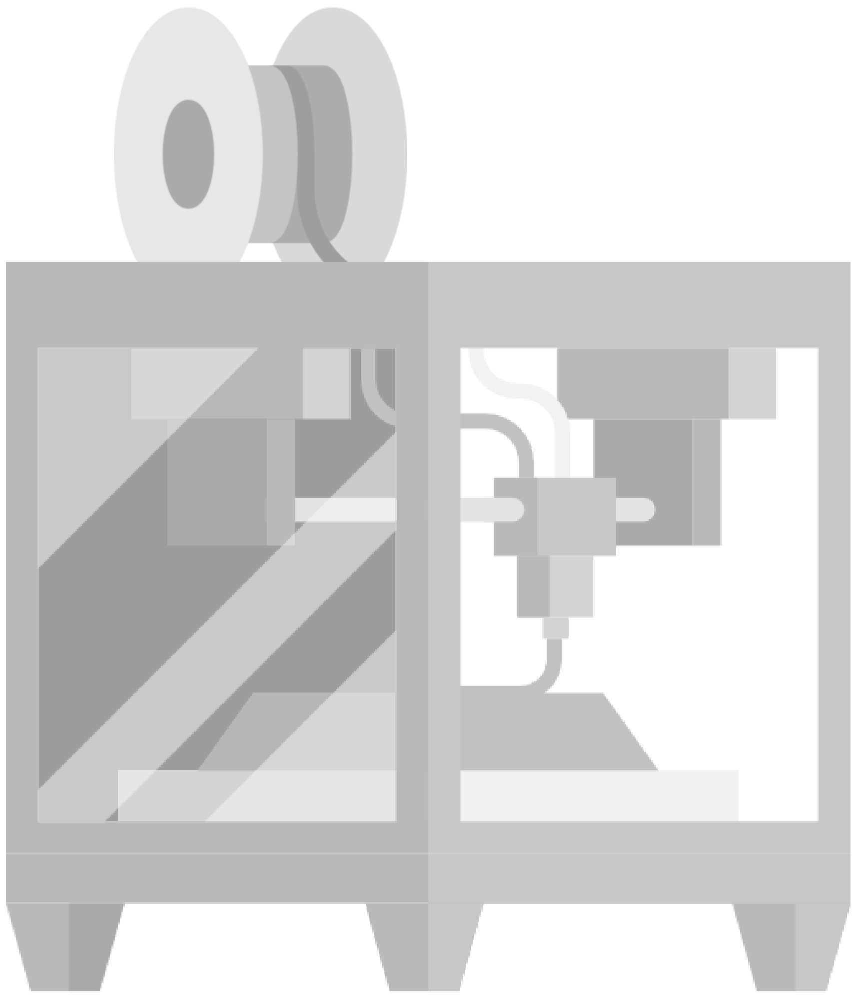
- Circle packing workshop:
http://www.asworkshop.cn/wp-content/uploads/2017/05/Circle-Packing-Pavillion-Intelligent-Building-Technology-Research.pdf

- packed pavilion:
http://packed-pavilion.blogspot.it/p/concept.html

- Packing Circles:
http://www.geometrie.tugraz.at/wallner/packing.pdf

- Searching for a full circle packing code:
http://www.designcoding.net/searching-for-a-full-circle-packing/

-Ken Stephenson (mathematician):
http://www.circlepack.com/books.html



CHAPTER 2

Additive Manufacturing developments in Architecture and its Potential

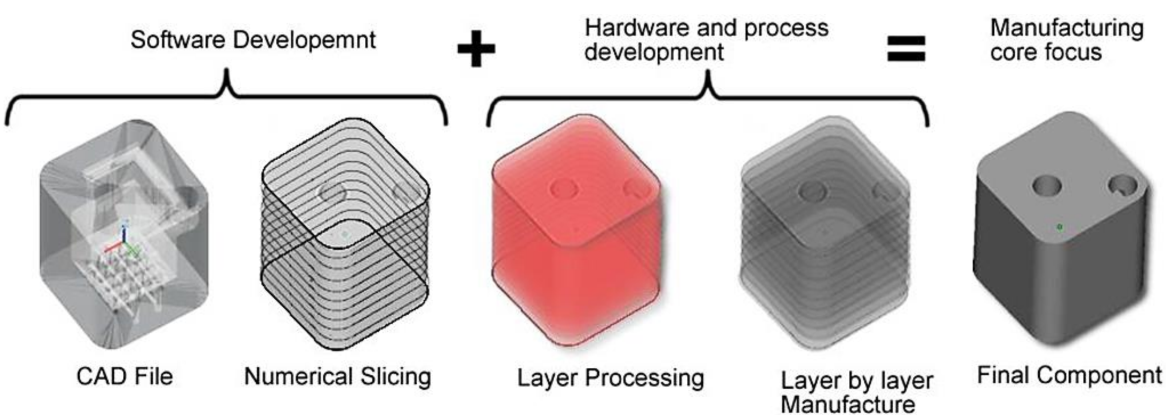
3D-printing is a term to describe technology used for the rapid production of 3D objects directly from digital computer aided design (CAD) files, Today, 3D printers can process a wide variety of materials and produce fully functional components. This Chapter is starting by demonstrating the importance of Additive Manufacturing it is discussed that 3D-Printing is a new industrial revolution which is called mass customization and it will influence on supply chain, The chapter will continue by presenting different AM technologies in general and introducing FDM 3d-printing in specific, the main objective of this chapter is opening the discussion of the possible use of recycled plastic in 3d-printers, this part will be a preface for the next chapter which is around recycling plastic more practically. The AM technology is fluid and still evolving, in this chapter the importance and the possible potentials and treats will be discussed.

Key-words: Additive Manufacturing, Supply chain, industrial revolution, Mass customization, PET, virgin Filament, Recycled Filament, Extruder.

What is Additive Manufacturing

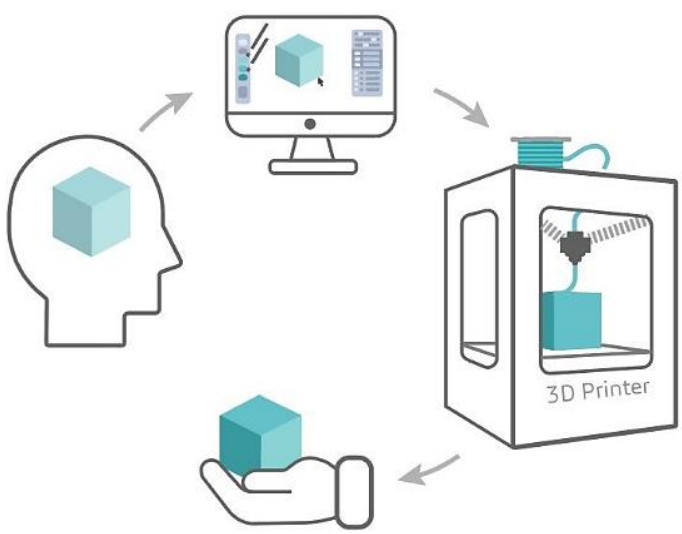
Additive manufacturing (AM) describes the technologies that build 3D objects by adding layer-upon-layer of material to build products. Once a file is produced using a 3D modeling software, the additive manufacturing machine (otherwise known as 3D printers) reads the data from the file and lays down successive layers of material to create a 3D object.

While the technology was first introduced in the early 1980's, its first uses were focused on prototyping and to visualize models in preproduction. Since then, additive manufacturing has evolved and is being used to create end-use products across almost all industries. More specifically Additive Manufacturing (AM) is defined by a set of technologies that are translating virtual model data into physical objects in rapid and simple way. The data is broken down into a series of 2D cross-sections of a finite thickness. These cross-sections are fed into AM machines so that they can be combined, adding them together in a layer-by-layer sequence fabricating the final geometry [Gibson et al, 2014], Products created using additive manufacturing techniques can be made in a variety of materials, from plastics to metals to ceramic. The technology is fluid and still evolving, and new materials are introduced at a more rapid pace than ever before.



Additive Manufacturing Potentials

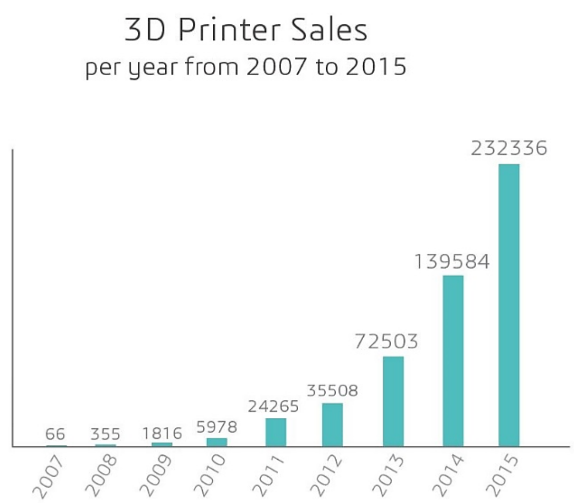
One of the main benefit of AM becomes the rapid nature of the process of the built which is related to the speeding up of the overall manufacturing, usually performed in a single step and almost entirely with the use of computers. These aspects can significantly bridge the gap between design and fabrication, reducing the number of the project stages through the implementation of a direct design-built system.
AM gives freedom to innovation, moving away from the notion of design as a static procedure and enabling architects and engineers to test multiple iterations simultaneously with minimal additional costs [Gibson et al, 2014] Furthermore, the process enables the fabrication of complex structures, ranging from the overall geometry or a part of it to the topology of its internal organization to the spatial distribution of its material composition.
Along with the freedom of fabrication though, increases also the design challenges to include representation and optimization of intricate geometries and functionally graded structures. Unlike other fabrication processes like milling, cutting, etc., additive manufacturing results in almost no waste of raw materials due to the nature of the process itself – starting an empty building plate and adding only the necessary material. The fabrication can be additionally optimized to reduce the amount of material needed by implementing internal air gaps or open lattice structures into the design. The compressed manufacturing process combined with these characteristics equate to a significantly environmental footprint. Layer-based manufacturing allows us to integrate structural and environmental optimization directly into the design stage decreasing in time and use of resources [Duro-Royo et al, 2014]
AM is not only changing the way we produce things but is also affecting logistics, supply change and shipping. Currently the transportation of goods around the world consume vast use of natural resources, this system is becoming highly unacceptable in the conditions of growing resources scarcity and environmental crisis [Bolinger et al, 2010] The days of Mega or even Giga factories are gone, factories that consume tremendous amounts of time and energy to fabricate products, a more sustainable and flexible factory is uprising and growing which is called micro factories, these diminutive factories drastically changes how we produce large consumer goods for unique local needs [Local Motors, 2015]

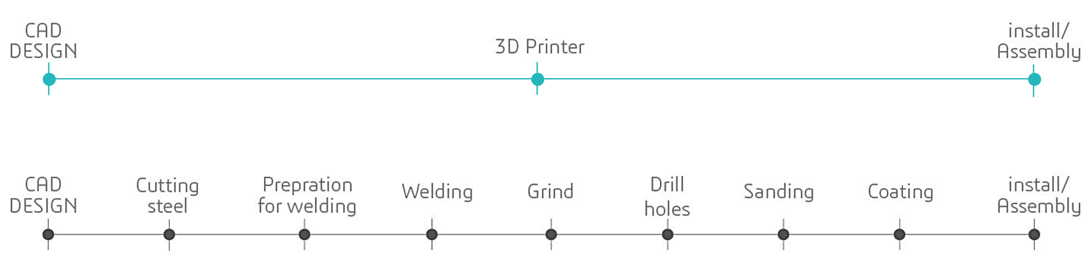


The recent advancement in the field of digital design and fabrication gives us the opportunity to eliminate the transportation related costs by implementing a streamline manufacturing process instead of the traditional centralized model. The technologies that underlie AM enable the rapid, flexible and cost-efficient design and production across many applications and industries around the world. Layer based manufacturing makes it to transform digital models into concrete physical objects almost simultaneously and at the same location or at any other location in the world "just-in-time", "on-demand" manufacturing [Lisbon, 2013], on the other hand, the growth of the AM industry leads to development of innovative product ideas and component designs, new processes and technologies novel materials and specialized softwares. Local communities and interested individuals can contribute of these processes.
This can consequently help creating new jobs and boost local economies, generating a sustainable employment system. This requires significantly lower energy consumption compared to centralized manufacturing and product distribution models which has already mentioned requires long-distance transportation of goods and materials. [Gibson et al, 2014] this way, AM technology can be considered as a 0 km factory. Although, AM technology is still a nascent and maturing but it continues to evolve rapidly both in response to and as a main driving force behind a new industrial paradigm, referred to by many as a New Industrial Revolution. It is characterized as a shift from mass production to massive customization.

- The first Industrial Revolution brought mechanization, centralized factories and industrial capitalists.
- The second industrial Revolution brought the automation, the conveyor belt and the social division between white-collar and blue-collar work.

These two phenomena rejected the customization and the multi-functional and multi-performative design. This industrial logic ensured constant and repeatable quality, but at the same time limited innovation, differentiation and the range of what was buildable.





New Industrial Revolution

The new Industrial Revolution on the other hand, implies a transformation of architecture from top-down irreversible production chain into a democratic, flexible and bottom-up ecosystem. Architecture will have the opportunity to incorporate the two seemingly distinct worlds of digital and material to create an emerging reality, synthesis of data, material, programming, computation and fabrication. Using novel tools and methods for design and manufacturing, architects can keep the control over the data flow and the intricate interaction between hardware and software, furthermore, with the advancement of additive manufacturing in the last decades we have the possibility to reconsider mass-customization, where an item can be produced according to the specific needs of the design but in an efficient way and without losing its initial functionality. Layer manufacturing also implements a continuous digital workflow that similarly to the traditional industrial logic comprises a coordination module but, in this case, it is adapted to the novel technological scenario. The superior element in such a process is the generative algorithm which produces data subsequently transformed into a numeric control programming language (G-code). Form is differentiated from the fundamental principles organizing the different elements within the manufactured component. None of the components is considered as an ideal primary model, every element might differ in geometry and form if the intricate logical interrelations are accurate. The bigger the variation and the complexity, the higher is the value and the benefits of using AM machine [Bollinger et al, 2010]

- Massive Customization
- Democratic and innovative Design
- flexible and bottom-up ecosystem
- Using novel tools and methods for design and manufacturing

This

consideration leads to an important aspect of the changing notions of architecture:

The shift from geometry conceived as and external regulator of materials to a notion that recognizes the inherent performances and behaviors of matter. The blurring boundaries between form, matter and function are pushing the architect away from the essentialist concept that matter is formless, and geometry should be imposed over it regarding its own capacities for self-organization and morphogenesis. The role of the architect in this novel field is also changing, Am and material practices offer architects the opportunity to question some of the restrictive assumptions that are deeply embedded in modernist design thinking and reinforced by traditional industrial chain logics. Thanks to many advancements now we can apply strategies for form-generating bringing maximum performance with minimal resources through local material property variation and optimization. This approach might result into a more integrated construction system avoiding the strict separation between different building components that are typically mass-produced and not adaptable and customizable to the need of the architecture [Oxman, 2010]

Does it exist a 3D-Printer for Architecture?

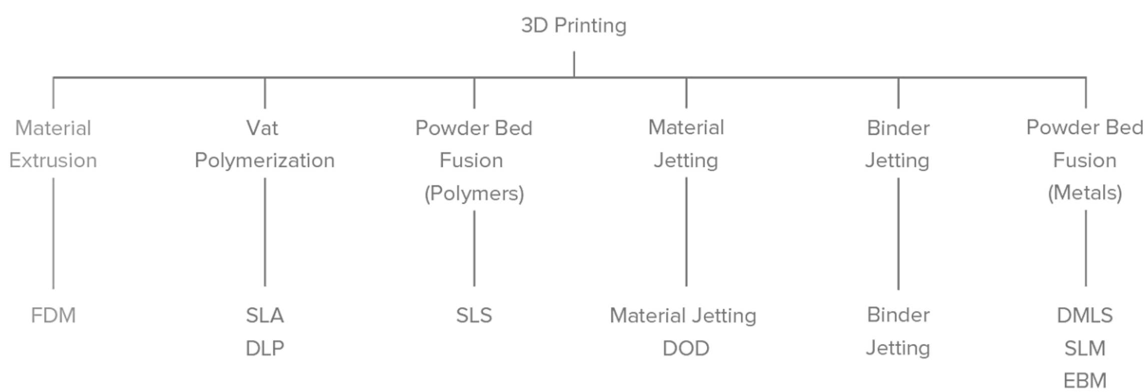
Every additive fabrication approach brings advantages and disadvantages in its process. Extrusion-based machines are usually not expensive, and material used are commonly cheaper than other additive technologies. However often demonstrating good mechanical properties, and they have formal limitations in overhanging structures. Differently, all those technologies which include laser beams results generally more expensive both in machines, material and maintenance costs. Although guaranteeing an incredible design freedom and precision.

A building design construction process as we know it today is made by dozens of different machines, working at different scales. With different materials and different roles into incredibly complex realm of constructions. Therefore, it appears ambitious to define a unique model of fabrication for a whole building, but it is more convenient to think that additive manufacturing maybe be integrated in traditional construction operations, and that different additive techniques may be employed for different applications.

From this technological review it is nevertheless evident that additive manufacturing in general is a technology still under dramatic developments, which started being fruitful and productive for experimental applications but that seems not yet ready for a huge and complex and competitive market such as constructions. Furthermore, it is noticeable that additive fabrication processes have not been investigated for architecture and constructions as much as in other fields, such as design, but also aeronautics. Where small objects in small series but with incredible details appears to be an immediate advantage.

Different Printing Techniques

An additive manufacturing process which employs liquid ultraviolet curable photopolymer "resin" and an ultraviolet laser to build parts one layer at a time. For each layer, the laser beam traces a cross-section of the pattern on the surface of the liquid resin. Exposure to the UV laser light cures and solidifies the pattern traced on the resin and fuses it to the layer below. After the pattern has been traced, the platform drops slightly (the distance is generally equal to the thickness of a single layer) and a resin-filled blade sweeps across the cross section of the part, re-coating it with fresh material. On this new liquid surface, the subsequent layer pattern is traced, again fusing it to the previous layer.



Map of different 3D printers

Fused Deposition Modeling (FDM)

Fused Deposition Modeling (FDM), or Fused Filament Fabrication (FFF), is an additive manufacturing process that belongs to the material extrusion family. In FDM, an object is built by selectively depositing melted material in a pre-determined path layer-by-layer.
The materials used are thermoplastic polymers and come in a filament form. FDM is the most widely used 3D printing technology: it represents the largest installed base of 3D printers globally and is often the first technology people are exposed to. In this article, the basic principles and the key aspects of the technology are presented as shown below in Fig.2. 1 and Fig.2. 2.

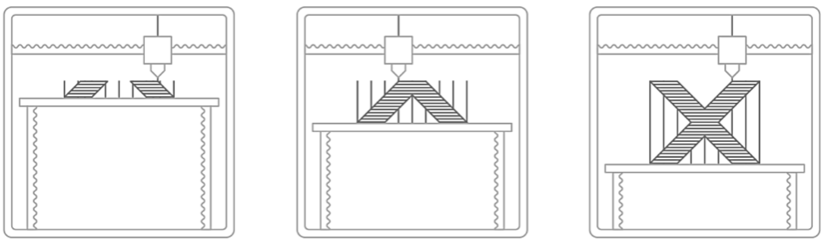


Fig.2. 1
https://www.3dhubs.com/

Printer Parameters: Most FDM systems allow the adjustment of several process parameters, including the temperature of both the nozzle and the build platform, the build speed, the layer height and the speed of the cooling fan. These are generally set by the operator, so they should be of little concern to the designer.
What is important from a designer's perspective is build size and layer height:
The available build size of a desktop 3D printer is commonly 200 x 200 x 200 mm, while for industrial machines this can be as big as 1000 x 1000 x 1000 mm. If a desktop machine is preferred (for example for reducing the cost) a big model can be broken into smaller parts and then assembled.

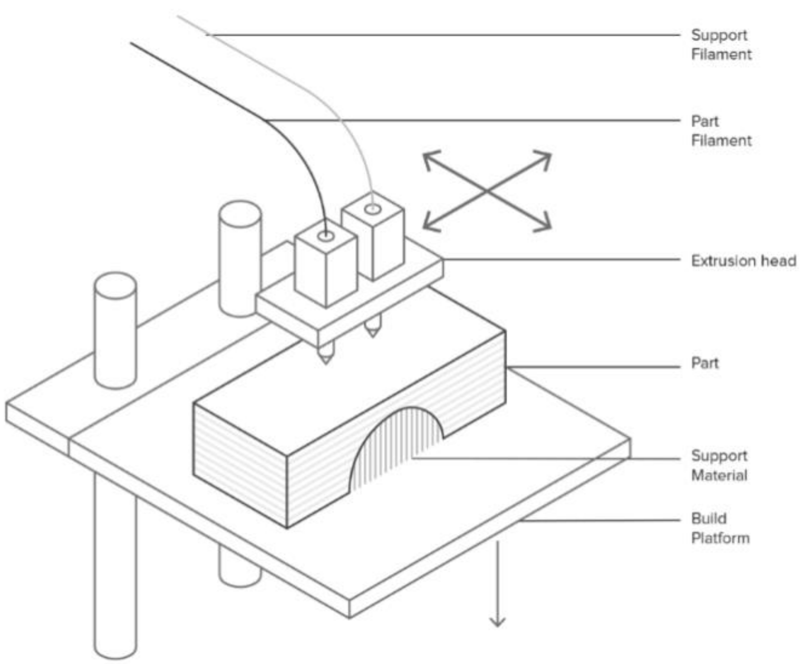
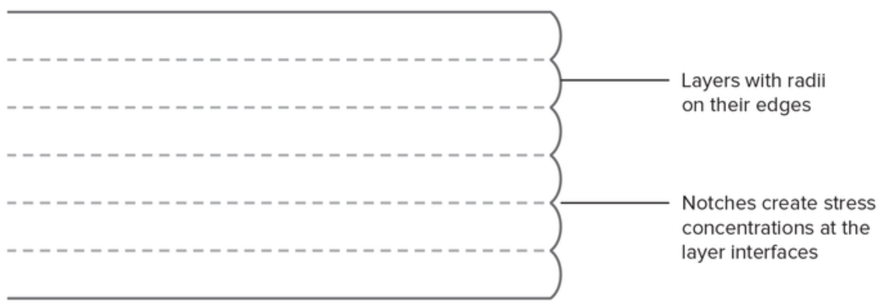


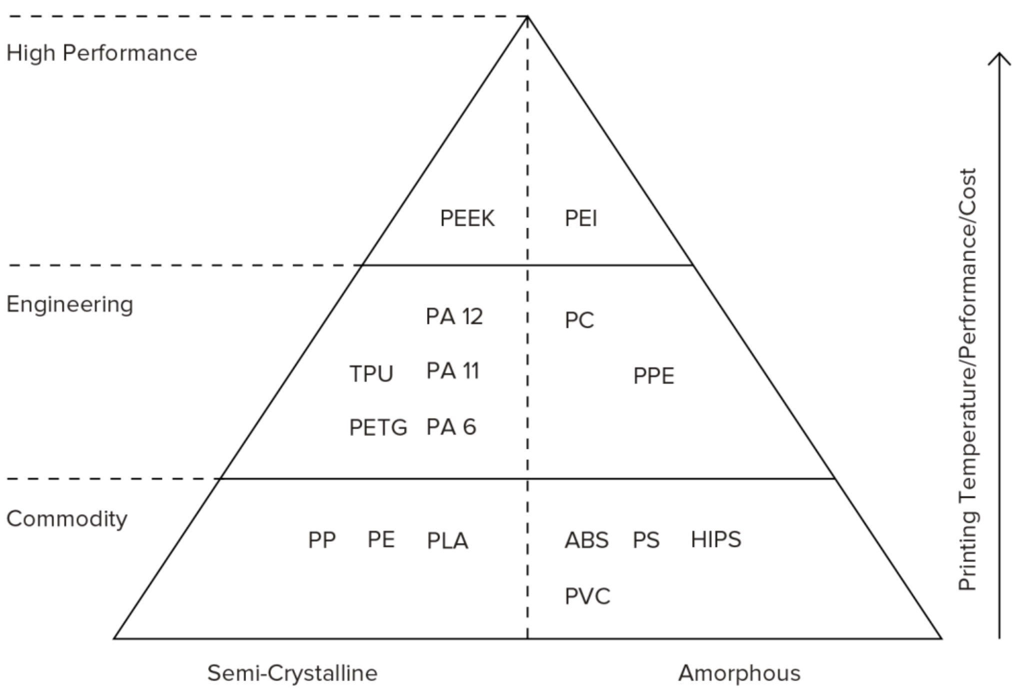
Fig.2. 2
https://www.3dhubs.com/

Layer Adhesion: Good adhesion between the deposited layers is very important for an FDM part. When the

molten thermoplastic is extruded through the nozzle, it is pressed against the previous layer. The high temperature and the pressure re-melts the surface of the previous layer and enables the bonding of the new layer with the previously printed part.
Moreover, since the molten material is pressed against the previous layer, its shape is deformed to an oval. This means that FDM parts will always have a wavy surface, even for low layer height, and that small features, such as small holes or threads may need to be post processed after printing.



Common FDM Materials:
One of the key strengths of FDM is the wide range of available materials. These can range from commodity thermoplastics (such as PLA and ABS) to engineering materials (such as PA, TPU, and PETG) and high-performance thermoplastics (such as PEEK and PEI).



Stereolithography (SLA)

An additive manufacturing process which employs liquid ultraviolet curable photopolymer "resin" and an ultraviolet laser to build parts one layer at a time. For each layer, the laser beam traces a cross-section of the pattern on the surface of the liquid resin. Exposure to the UV laser light cures and solidifies the pattern traced on the resin and fuses it to the layer below. After the pattern has been traced, the platform drops slightly (the distance is generally equal to the thickness of a single layer) and a resin-filled blade sweeps across the cross section of the part, re-coating it with fresh material. On this new liquid surface, the subsequent layer pattern is traced, again fusing it to the previous layer. as represented below in Fig.2. 3 and Fig.2. 4.

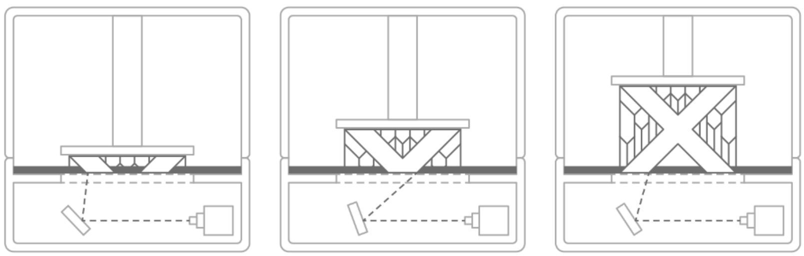


Fig.2. 3
https://www.3dhubs.com/

Here is how the SLA fabrication process works:

- The build platform is first positioned in the tank of liquid photopolymer, at one-layer height for the surface of the liquid.
- Then a UV laser creates the next layer by selectively curing and solidifying the photopolymer resin. The laser beam is focused in the predetermined path using a set of mirrors, called galvos. The whole cross-sectional area of the model is scanned, so the produced part is fully solid.
- When a layer is finished, the platform moves at a safe distance and the sweeper blade re-coats the surface. The process then repeats until the part is complete.
- After printing, the part is in a green, no-fully-cured state and requires further post processing under UV light if very high mechanical and thermal properties are required.

The liquid resin is solidified through a process called photopolymerization: during solidification, the monomer carbon chains that compose the liquid resin are activated by the light of the UV laser and become solid, creating strong unbreakable bonds between each other.

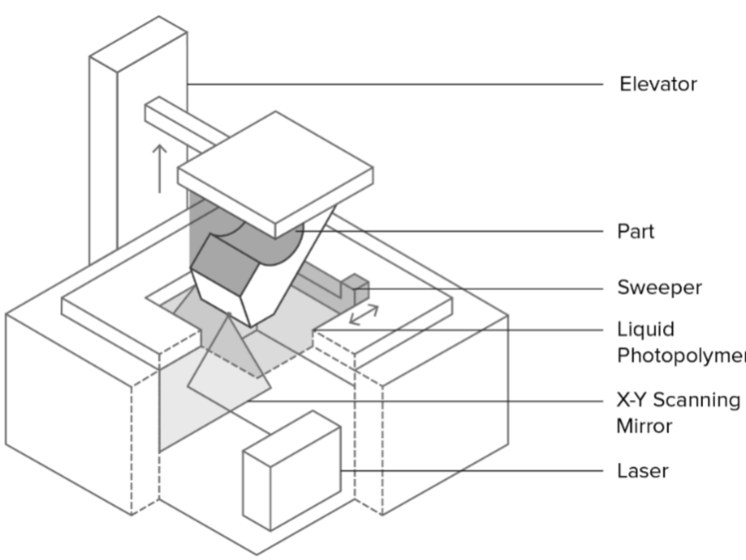


Fig.2. 4
https://www.3dhubs.com/

Selective Laser Sintering Selective Laser Sintering (SLS)

A technique that uses a laser sinter powdered material, aiming the laser automatically at points in space defined by a 3D model, binding the material together to create a solid structure. Using a high-power laser to selectively fuse thin layers of powdered materials, the laser scans cross-sections generated from the file on the surface of a powder bed. After each section is scanned, the bed is lowered, and a new layer of material is applied. The process repeats until the object is completed. SLS is a great use for rapid prototyping and for low-volume production of component parts.
Here in Fig.2. 5 and Fig.2. 6 is shown how the SLS fabrication process works:

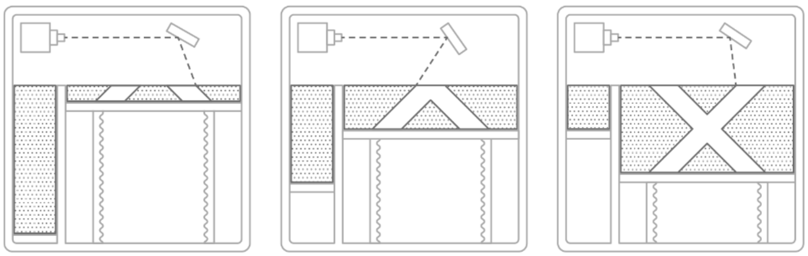


Fig.2. 5
https://www.3dhubs.com/

- The powder bin and the build area are first heated just below the melting temperature of the polymer and a recoating blade spreads a thin layer of powder over the build platform.
- A CO_2 laser then scans the contour of the next layer and selectively sinters (fuses together) the particles of the polymer powder. The entire cross section of the component is scanned, so the part is built solid.
- When the layer is complete, the build platform moves downwards and the blade re-coats the surface. The process then repeats until the whole part is complete.

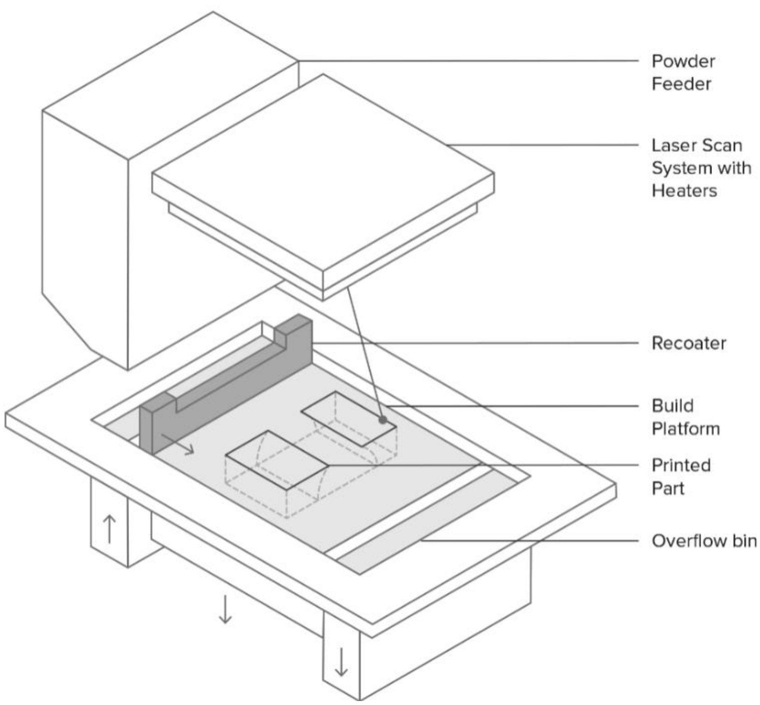


Fig.2. 6
https://www.3dhubs.com

Direct Metal Laser Sintering (DMLS)

Selective Laser Melting (SLM) and Direct Metal Laser Sintering (DMLS) are two metal additive manufacturing processes that belong to the powder bed fusion 3D printing family. The two technologies have a lot of similarities: both use a laser to scan and selectively fuse (or melt) the metal powder particles, bonding them together and building a part layer-by-layer. Also, the materials used in both processes are metals that come in a granular form.

Metal 3D printing is most suitable for complex, bespoke parts that are difficult or very costly to manufacture with traditional method. In Fig.2. 7 and Fig.2. 8 it is clear how it works:

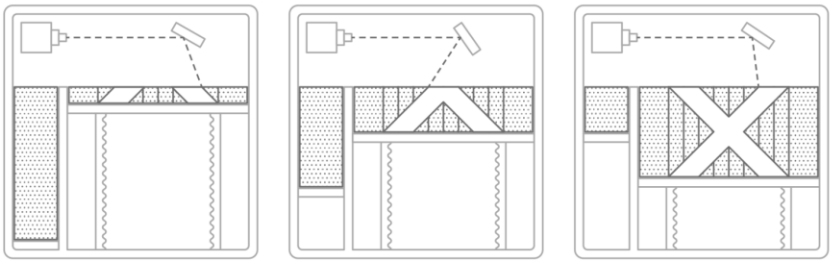


Fig.2. 7
https://www.3dhubs.com

The basic fabrication process for SLM and DMLS are very similar. Here is how it works:

- The build chamber is first filled with inert gas (for example argon) to minimize the oxidation of the metal powder and then it is heated to the optimal build temperature.
- A thin layer of metal powder is spread over the build platform and a high-power laser scans the cross-section of the component, melting (or fusing) the metal particles together and creating the next layer. The entire area of the model is scanned, so the part is built fully solid.
- When the scanning process is complete, the build platform moves downwards by one-layer thickness and the recoated spreads another thin layer of metal powder. The process is repeated until the whole part is complete.

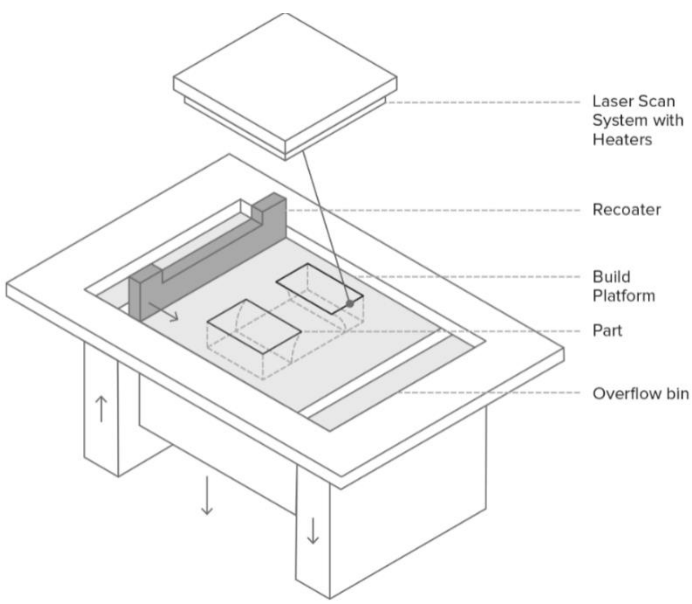


Fig.2. 8
https://www.3dhubs.com

Binder Jetting:

This term explains a process in which layers of material are bonded by selectively depositing a liquid binding agent to join powdered material. This process of additive manufacturing can print a variety of materials, such as metals, sands and ceramics. While other additive techniques use a heat source to bind materials together, Binder Jetting does not employ any heat during the build process. This process provides the ability to print large parts and can be more cost effective than other methods, Fig.2. 9 and Fig.2. 10.

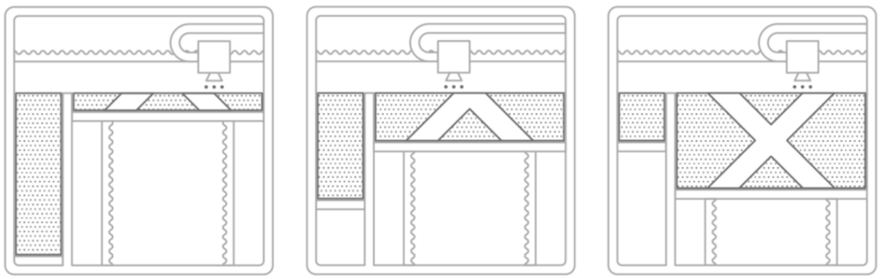


Fig.2. 9
https://www.3dhubs.com

Here is how the Binder Jetting process works:
- First, a recoating blade spreads a thin layer of powder over the build platform.
- Then, a carriage with inkjet nozzles (which are similar to the nozzles used in desktop 2D printers) passes over the bed, selectively depositing droplets of a binding agent (glue) that bond the powder particles together. In full-color Binder Jetting, the colored ink is also deposited during this step. The size of each drop is approximately 80 μm in diameter, so good resolution can be achieved.
- When the layer is complete, the build platform moves downwards and the blade re-coats the surface. The process then repeats until the whole part is complete.
- After printing, the part is encapsulated in the powder and is left to cure and gain strength. Then the part is removed from the powder bin and the unbound, excess powder is cleaned via pressurized air.

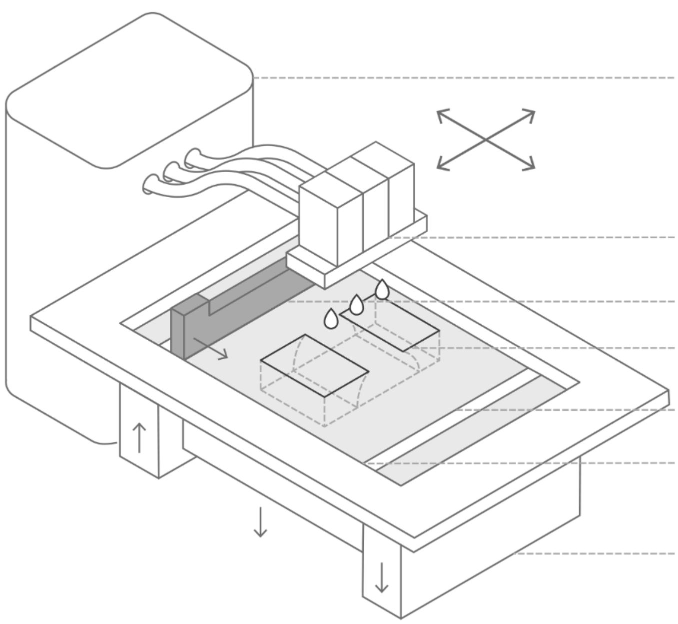


Fig.2. 10
https://www.3dhubs.com

Printing-Material Engineering

Earlier AM technologies were built around materials that were already available and that had been developed to suit other processes, however those original materials were far from ideal for architectural applications. For example, the early resin resulted in models that were brittle and that warped easily. As the technology of AM advanced, the material knowledge also developed according to demands, for example now Concrete, clay and even metal is being printed, despite of many advancements, it should be stated that AM technologies requires specific materials to produce effective results. Material Engineer researchers are constantly conceiving new material variations for 3D printing and one of the most important field of study is using recycled material as raw material in the attempt of reducing costs and sustainability approach, they try to improve their performances by many different tests.

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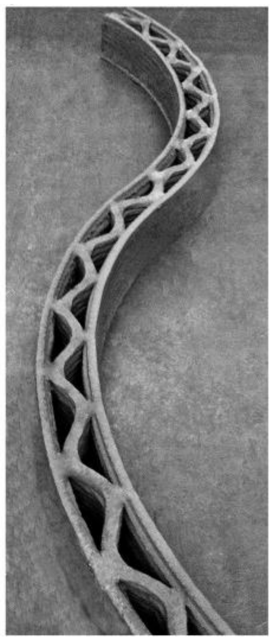
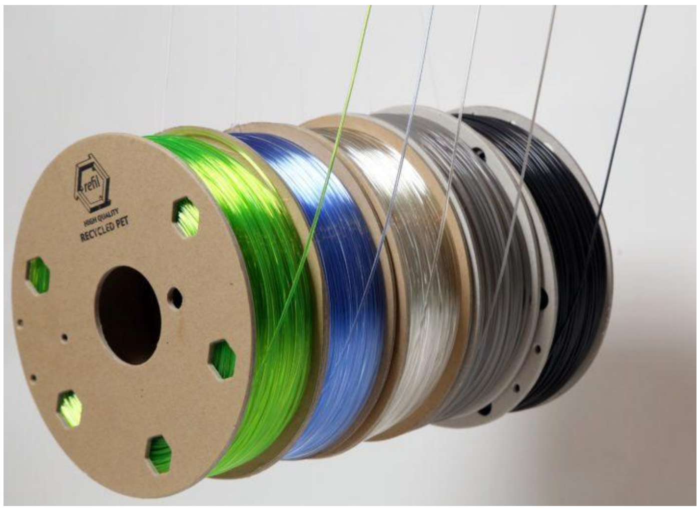


Egg-Shaped Pavilion, world's largest collectively 3D printed project by Dutch designer Michiel van der Kley,, Project EGG uses biodegradable polylactide (PLA) plastic. (2015)

A Research on differences Virgin and Recycled filaments PLA, PETG, PET

Choosing the right type of material to print a given object is becoming increasingly difficult, as the 3D printing market sees the regular emergence of radically new materials. In FDM 3D printing, PLA and ABS have historically been the two main polymers used, but their initial dominance was mostly fortuitous, so there should not be any major roadblocks for other polymers to play a key role in the future of FDM.
We are now seeing new products become more popular, both pure polymers and composites. In this study, we focus on the main pure polymers that exist in the market today: PLA, ABS, PET, Nylon, TPU (Flexible) and PC. We sum up the key differences between their properties in snapshot profiles so that users can make a quick decision about the best polymer to use for their application



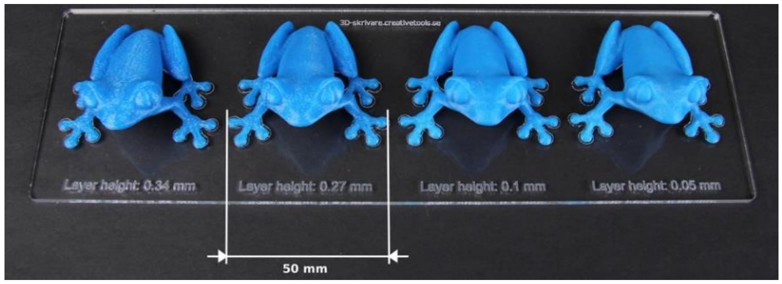
The Recycled and virgin Filaments are Provided by REFIL company. fully recycled ABS filament made from car dashboards and PET filament made from old PET bottles in Blue and Green colors, and fully Recycled PLA from white food packing. (http://www.betterfuturefactory.com/project/refil/)

In a recent research done by a group of material engineering students at polimi, they tested the mechanical properties (modulus and resistance attraction) and thermal characterization (resistance to temperature and humidity) of the object printed with FDM technique material. The aim of this research is to characterize the most widely used and easily available polymeric materials additive manufacturing (AM), i.e. PLA, PET and PETG, focusing particularly on a comparison between virgin and recycled material.
Tension stress resistance test was carried out by imposing a stroke of 1 mm / min, with room temperatures between 22 ° C and 24 ° C; the material that obtained the best results was the R-PETG, which average value of the stress at break was 38.30 MPa and of the Young's module of 15.90 GPa (for the sample having 100% infill). Tension Stress tests were carried out, with the same parameters also on samples with 75% and 50% infill to verify the variation of mechanical properties.
The thermal characterization was performed by placing the samples, with 50% infill, in a climatic chamber for two days at a temperature of 70 ° C and 90% humidity. In this last test, again the recycled materials have undergone dimensional changes more than the corresponding virgin, especially the R-PET, which it turned out to be the worst material in this case, with values always higher than 6.25%.
The results that from these two standard tests can be generalized in various fields; the result of this research helped a lot in the design of the barricade for which is the design part of this project, in the hot a humid climate of Dubai and choosing the right material.

Parameters that effect Printing in FDM 3D-printer

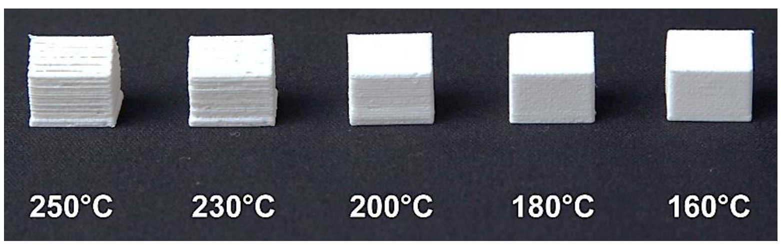
1. Effect of Layer Thickness:

The thickness of the layer is the height of each single layer that is deposited on the built plate and, subsequently continues, the larger thickness results less resolution and less adhesion between layers.



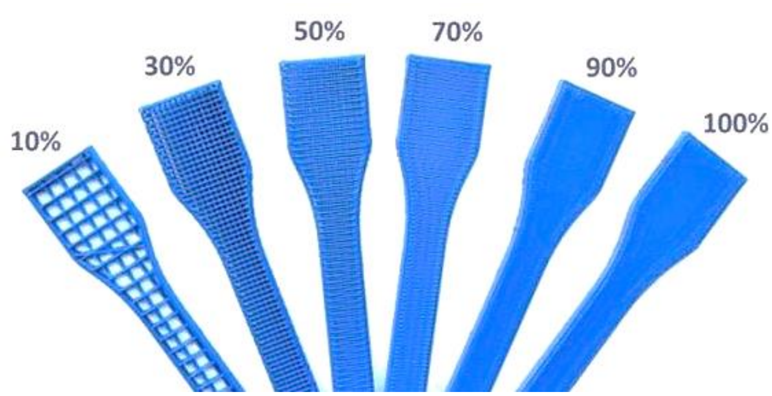
2. Effect of the Extrusion Temperature:

In the FDM the nozzle is responsible for both the final resolution of the object and the external temperature of the filament. The extrusion temperature is a fundamental parameter in the FDM, in fact it plays a role very important in determining the quality of the bond and adhesion between the layers and consequently the mechanical properties. Moreover, high temperature will result higher flow in material and fill the gaps and more adhesion between layers.



3. Effect of infill:

Infill is the amount of structure support inside the printed piece. Its value can vary between 0%, which corresponds to the case in which there are only external layers (wall) of piece, up to 100%. Setting the machine with values between 0% and 100% the object will be filled according to a selected pattern. As it is easy to predict, the effect of infill on mechanical strength is anything but negligible. In the article by Alvarez et al. a proportionality between infill and tensile strength of the specimens is highlighted. This relationship can be explained by the increase in the area resistant to the increase in the percentage of infill.



4. Effect of the Orientation:

The materials printed in FDM inherit an anisotropic behavior, as their mechanical behavior is not the same in all directions: therefore, the orientation of the individual strands or of the same specimens on the plate have a significant influence on the results obtained from the specimens.

5. Effect of the Printing speed:

Depending on the shape of the model and the travels of the extruder, this parameter effects the quality of the print, the more detailed shape needs a lower speed in printing.

In this research, dog bone specimens for mechanical tests were designed on Autodesk Inventor and square slabs for thermal tests, both printed with horizontal arrangement (flat). The FDM print of the specimens was made using a Delta Wasp 20x40 printer with a nozzle extruder of 0.7 mm. The printer, once switched on, heats the plate and the nozzle at the temperature chosen by the operator. The filament manufacturer provides a range of temperatures in which one can print, the ideal one is chosen based on the conditions imposed by software or the operator's experience. One time when the exact temperatures are reached, the extruder head deposits the filament and creates the object layer on layer, as seen in Fig.2. 12 as below.

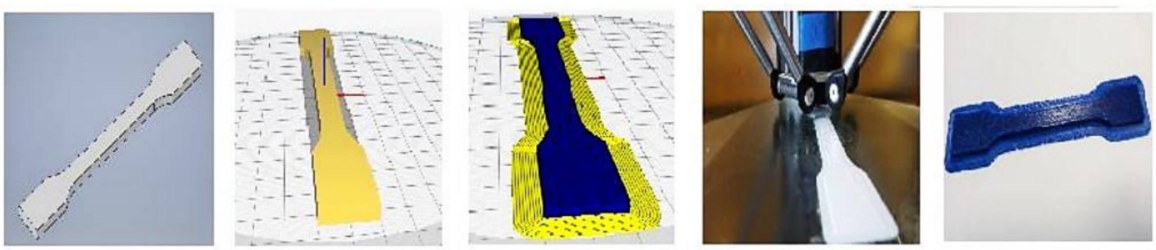


Fig.2. 12: This picture shows the Process of preparing the specimen for this research, Modeling, Slicing Software, infill Pattern, Printing and the Result.

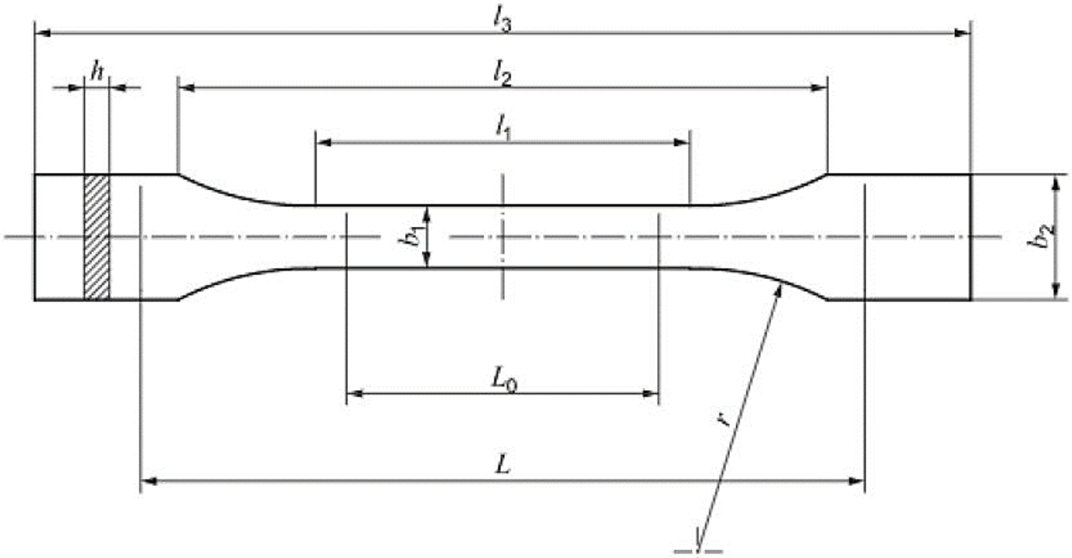


Fig.2. 13: The overall dimensions of the Speciment (dog bone): l_3: 170.0 - l_1: 80.0 - l_1: 109.0 - b_1: 10.0 - b_2: 20.0 - h: 4.0 - L0: 75.0 - L: 115.0

In the process of testing, these parameters were constant in the printing step:

• Layer thickness: affects the quality of the specimen. The value to 0.1 mm is used for both geometries;

• Nozzle size: this parameter has effects very similar to those due to the layer thickness. The nozzle with 0.7 mm diameter is used in this survey.

• Wall thickness: indicates the thickness of the external walls, the dimension must be equal or more than the nozzle diameter, the diameter chosen is equal to diameter of the nozzle which is 0.7mm, as a result, the wall number is equal to one.

• Print speed: has been set at 60 mm / s; in the initial phase it was chosen lower (about the 60% of 60 mm / s) to check the progress of printing of the first layers and then faster (100%); increasing the printing speed again would result in the formation of visible defects also naked eye;

• Travel speed: this is the speed of the extruder when lifting and not extruding filament and has been set equal to twice the print speed;

• Position of the axles: origin at the center of the plate;

• Flow: amount of material that the machine extrudes per second. It has been set to 100%.

These Parameters Varied during the test:

• Infill: how much volume of the model built on Inventor is filled by the material and how it is filled. By the variation of this parameter changes the mechanical properties of the final product; in the case of this study it was decided to fill 100%, 75% and 50% dog bone specimens to verify the trend of resistance and of the elastic modulus, while the slabs at 50% for problems related to time molding (in fact this geometry with a 100% infill took about 10 hours to come completed). The choice of the pattern fell on the filling with lines inclined at 45 ° for a layer e at -45 ° for the next and so on to create a three-dimensional network;

• Top and bottom thickness: indicate the number of layers to be filled above and below. They act as a support, providing a base of support, but they also have an aesthetic effect in that cover the object without showing the hollow interior. This parameter is irrelevant in the case of specimens 100% full, while it is important in the case of specimens with less filling. For 50% specimens and 75% have chosen a value equal to 0.2 mm to have the two upper layers and the two lower ones totally full and the rest with the chosen filling. For the plates a value equal to 0.4 mm.

• Brim width: it is one of the methods of adhesion to the printing plate selectable by Cura Ultimaker. The value of this parameter must be a multiple of 0.7 mm,For the dog bone a value of 4.5 mm was chosen. It is also useful to increase this parameter in the case of objects with a larger surface, as in the case of the square slab where a value has been chosen of 14 mm.

Thermo-Mechanical Study on Material Behavior

Tension tests in the material testing laboratory (LPM) were carried out on dog bone specimens of the Polytechnic of Milan with the Instron machine (n ° number 5994K9152) with a maximum load of 2kN. Before performing the tensile test, width and thickness were measured the resistant area of each specimen at three points to calculate a middle section. The tests were done on 18 specimens, one with 100% infill, one 75% and one 50% for each material: As a result, through these it is noticed how the PETG, both virgin and recycled, was the most resistant material.
The thermal tests were performed in the LPM (Structural Anchors Section) in the climatic chamber of environmental simulation Binder MKF720 (serial number 07-20870). A square plate of each material is inserted into the machine for 48 hours at 70 ° C and 90% humidity.

Fig.2. 13: This picture shows the comparison images of the specimens before and after the cycle in the climatic chamber

It has been noted that all the specimens that have undergone the treatment have a dimensional trend characteristic; it is therefore possible to draw the plate before and after treatment, as shown in the figure 30. The extent of dimensional change for qualitative purposes was assessed by carrying out the measurements reported in table 10, over significant distances. These were calculated with a rigid meter (sensitivity 1mm) because the variation is much higher than the sensitivity of the instrument, but also because a single specimen it is not significant to determine a unique behavior of the material with high precision. The initial dimensions of the plates, with this method of measurement, are consistent with those indicated in the 3D model (80x80x10 mm)

An overview in Mechanical Behavior of Virgin and Recycled form of PLA, PETG, PET

The results obtained from the tensile test carried out on the specimens are shown below. For each pair of materials, recycled and virgin, two graphs were drawn that compare virgin material with that recycled:

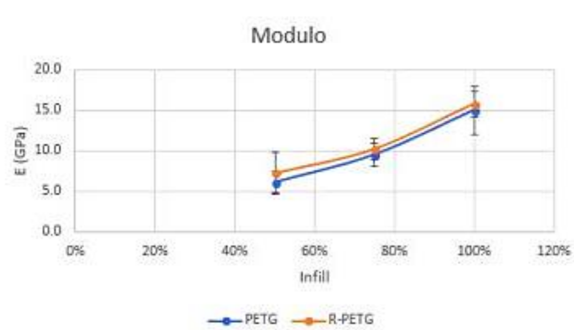
• On the left, the maximum breaking stress values obtained in function of the percentage of infill.

• The graphs on the right show the values of the elastic modulus (ordinate axis) in operation of the percentage of infill. The idea is to go to analyze a homogeneous material and equivalent to the real one in terms mechanical because the interest is to observe the mechanical properties of the object in such a way as to know if resist the loads to which it is subject even if the structure is not 100% full; this means that for characterize the material in relation to the percentage of infill, and not with respect to the real area of the section resistant, we must consider the latter as full. the level of effort X al which the 75% test specimen resists and the stress level Y, different from the previous one, to which the 100% test and dividing X and Y by the same value A you will get two different values index of the variation of mechanical properties with the infill. Instead, dividing X and Y for A and A1 (real sections) should be obtained same result, index in this case of the resistance of the material.

- **PET e R-PET**

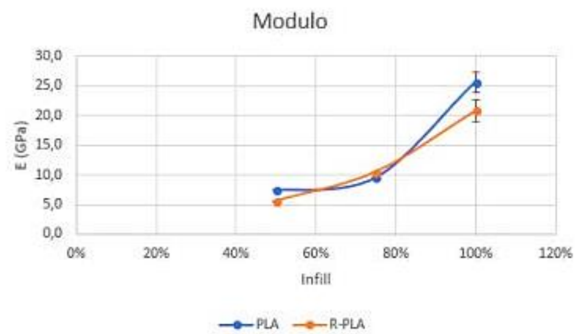
The results obtained above show that the differences between the two materials are minimal. However, it can be notice how the recycled PET, against all odds, has obtained similar values and some percentages (50% e 100% of infill) even higher than virgin PET. These results could be explained by a possible increase of the crystallinity due to the stretch imposed during the re-extrusion of the material during the recycling process. This hypothesis and further considerations on the transformation undergone by the recycled material it can be confirmed with an analysis on the microstructure of the material, which can be performed for example with a SEM electron microscope; in this case, more oriented chains should be observed in the extrusion direction for the recycled filament with respect to the virgin filament.

- **PETG E R-PETG**



It is shown in the previous graphs, a comparison between PETG and R-PETG, it can be stated that the recycled material presents not only values comparable with the virgin one, but even higher. The R-PETG employed in this work comes obtained from processing waste, and not from materials used and therefore at the end of life. The recycled material therefore appears to be purer than a normal recycled, and this, together with a possible increase of the crystallinity due to the stretching introduced during the re-extrusion, could explain the very good results obtained from recycled PETG.

- **PLA E R-PLA**



In this case, Figure above shows that the values obtained are more similar to those envisaged, since the PLA virgin has exhibited better behavior at almost all the percentages of infill (there is a deviation of the trend for R-PLA at 75%). In this case it is not possible to evaluate the quality of the recycled specimen based on a possible higher crystallinity induced to the recycling process since, according to the PLA used, there may be filaments of amorphous or semi-crystalline material.

It is clear from compared values of the stress-strain graphs, previously reported, as the specimens both virgin and recycled with a higher percentage of infill exhibit better mechanical properties. How long regards the elongation at break there is a lower regularity as not all samples having 100% of infill have higher percentage stretch values than specimens with lower fill percentage. This is the case, for example, of PET and R-PET, materials for which specimens having a 50% infill have exhibited a elongation at break greater than the 75% filled specimen and, in the case of the virgin specimen, even greater of the sample having 100% filling. For stress-strain graphs, they were used, for each material, the values obtained from the breakdown graphs and the most representative specimen form, using the one with behavior more like the mean of elongation at break. From the results in Table 8 shows that there is no linear trend between the reduction of% and maximum effort; this can be explained by the fact that the effective resistant area of the specimen does not coincide with ½ (for the 50% test piece) or with ¾ (for the 75% test piece) of the 100% test area. This effect can be due to the presence of unavoidable random porosity and defects induced by the printing technique.

Fig.2. 14: This picture shows the results of tensile testing on different prints by different filaments.

Conclusion:

3D printing allows to obtain complex geometries and build almost anything, additive manufacturing reduce both the costs of transporting the materials and the number of pieces needed to make one object. The presence of numerous variables, combined with the fact that the 3D printing technology is newly developed, ensures that we do not have enough data to understand the better the thermal and mechanical responses of the objects produced with this technology; the values that are presented coming from the various characterizations and they are not in fact standardized, as there are not any specific regulations for 3D printed objects. This, combined with the slowness of the process and from economical point of view often higher than traditional methods, can explain the low use of 3D printing in the industrial world.

One of the main limitations of the FDM technique is the formation of a non-homogeneous structure due mainly to the method of deposition of the material, but also to an uneven distribution of the heat inside the room: according to some research it would be necessary to use printers with cameras thermostatic or with a good ventilation system to minimize the last phenomenon. From the tests in the climatic chamber it has been resulted that, given the large dimensional variations, it is not possible to use 3D molded frameworks for jets that reach temperatures of 70 ° C. This does not indicate that the project is completely impossible, in fact further tests should be carried out at lower temperature levels for identify the ideal working conditions of each material.

It is also important to have a more detailed characterization from the mechanical point of view because the results obtained from tensile tests are related to the filling direction of the layer and the printing parameters used; the values of these tests can be very different using different settings, so it is a much deeper study is needed, verifying the effect of each individual setting on the property of the building.

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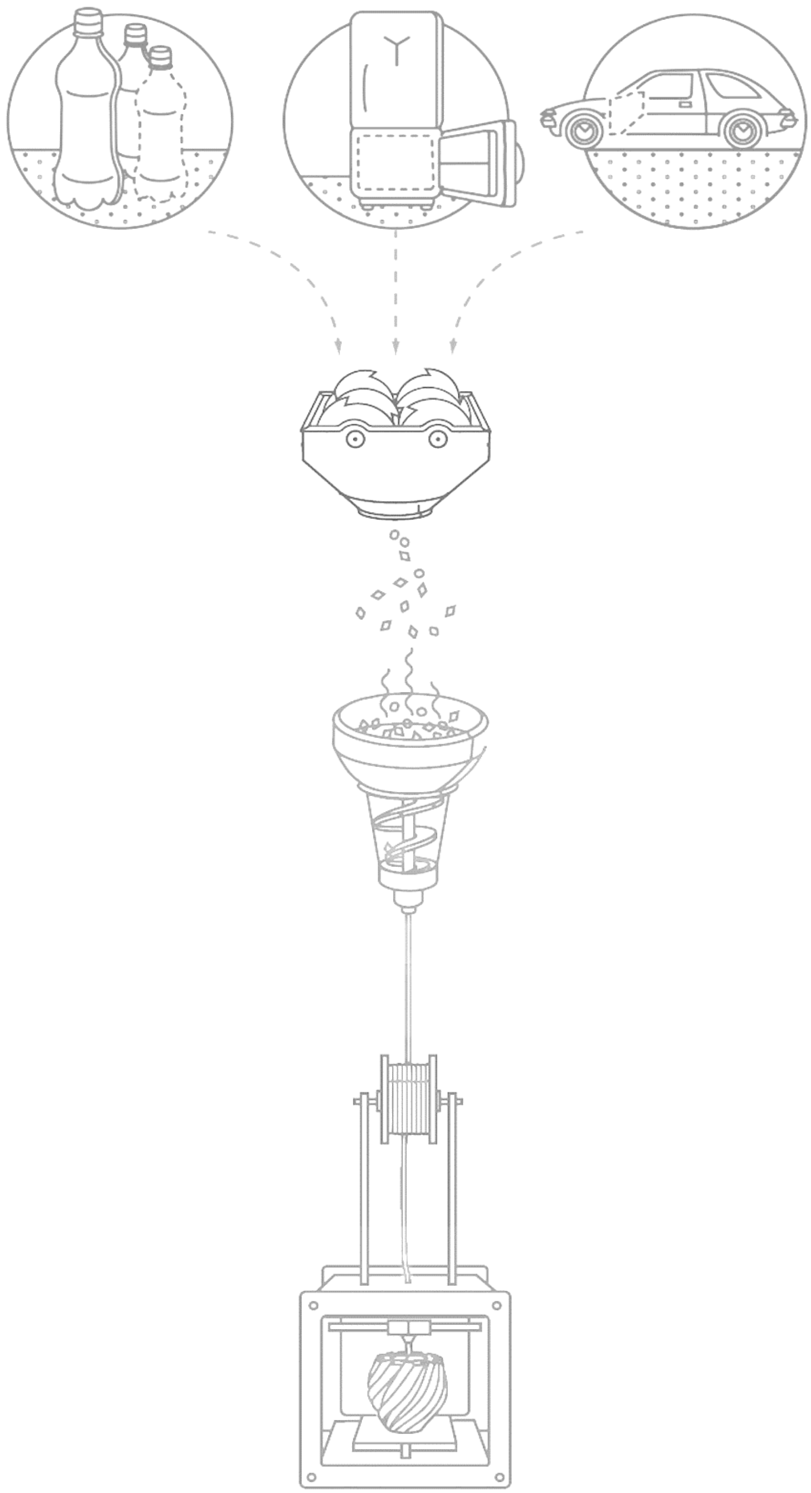


CHAPTER 3

Recycled Material and Techniques for 3D-Printing

The emergence of advanced manufacturing technologies, coupled with consumer demands for more customized products and services, are causing shifts in the scale and distribution of manufacturing. In this chapter, consideration is given to the the possibility of using recycling technology in additive manufacturing, according to a recent research in polimi, testing three different filament materials, PLA, PET and PETG, they tested both virgin and recycled filament from mechanical behavior and thermal resistance, the result was surprisingly supporting the fact that a recycled filament is performing better, it is a validation for the discussion in this chapter, on why using recycled filament, how to prepare it and what plastics can be recycled and used for 3D printing, and the importance of mega events and large-scale exhibitions with huge amount of plastic waste and large number of visitors. The consequences of adopting this novel production technology on urban design and architectural design sustainability are not well understood and this exploratory study draws on publically available data to provide insights into the impacts of additive manufacturing on sustainability. As an immature technology, there are substantial challenges to these benefits being realized at each stage of the life cycle. This chapter summarizes these advantages and challenges and discusses the implications of additive manufacturing on sustainability in terms of the sources of innovative design, business models, and the configuration of value chains.

Key-words: Sustainability, Recycling, Filaments, Extrusion, PETG,

Importance of using recycled material in AM Technology

The adoption of additive manufacturing (AM) and other advanced manufacturing technologies appears to herald a future in which value chains are shorter, smaller, more localized, more collaborative, and offer significant sustainability benefits.
Additive manufacturing mimics biological processes by creating products layer-by-layer. It is inherently less wasteful than traditional subtractive methods of production and holds the potential to decouple social and economic value creation from the environmental impact of business activities. Among the many potential sustainability benefits of this technology, three stand out:

- Improved resource efficiency: improvements can be realized in both production and use phases as manufacturing processes and products can be redesigned for AM;
- Extended product life: achieved through technical approaches such as repair, remanufacture and refurbishment, and more sustainable socio-economic patterns such as closer relationships between producers and consumers;
- Reconfigured value chains: shorter and simpler supply chains, more localized production, innovative distribution models, and new collaborations

However, despite these prospective benefits, AM has not been sufficiently explored from a sustainability perspective. While it could be an enabler and a driving force for improved industrial sustainability, the consequences of its implementation on the industrial system could lead to an alternative scenario in which less eco-efficient localized production, customer demands for customized goods, and a higher rate of product obsolescence combine to bring about increased resource consumption.

Different forms of Polymers and their behavior

Polymeric materials can be classified as thermosetting Polymers and thermoplastic Polymers. Thermoplastic Polymers soften and melt when heated, they may be recycled. Thermosetting Polymers stay hard, and eventually burn when heated, they may not be recycled.
Thermoset polymers refer to the irreversible polymerization and this type of polymer is cured by chemical reaction or heat and becomes infusible and insoluble material. Thermoplastics are made up of linear molecular chains and this polymer softens on heating and hardens when cooled, Plastics are organic polymeric materials consisting of giant organic molecules. Plastic materials can be formed into shapes by one of a variety of processes, such as extrusion, molding, casting or spinning. Modern plastics (or polymers) possess several extremely desirable characteristics; high strength to weight ratio, excellent thermal properties, electrical insulation, resistance to acids, alkalis and solvents, to name but a few.
Thermoplastics make up 80% of the plastics produced today. Examples of thermoplastics
Include:
• polyethylene terephthalate (PET) used in bottles, carpets and food packaging;
• high density polyethylene (HDPE) used in piping, automotive fuel tanks, bottles, toys,
• low density polyethylene (LDPE) used in plastic bags, cling film, flexible containers;
• polypropylene (PP) used in food containers, battery cases, bottle crates, automotive
parts and fibers;
• polystyrene (PS) used in dairy product containers, tape cassettes, cups and plates;
• polyvinyl chloride (PVC) used in window frames, flooring, bottles, packaging film, cable

insulation, credit cards and medical products.
There are hundreds of types of thermoplastic polymer, and new variations are regularly being developed. In developing countries, the number of plastics in common use, however, tends to be much lower.

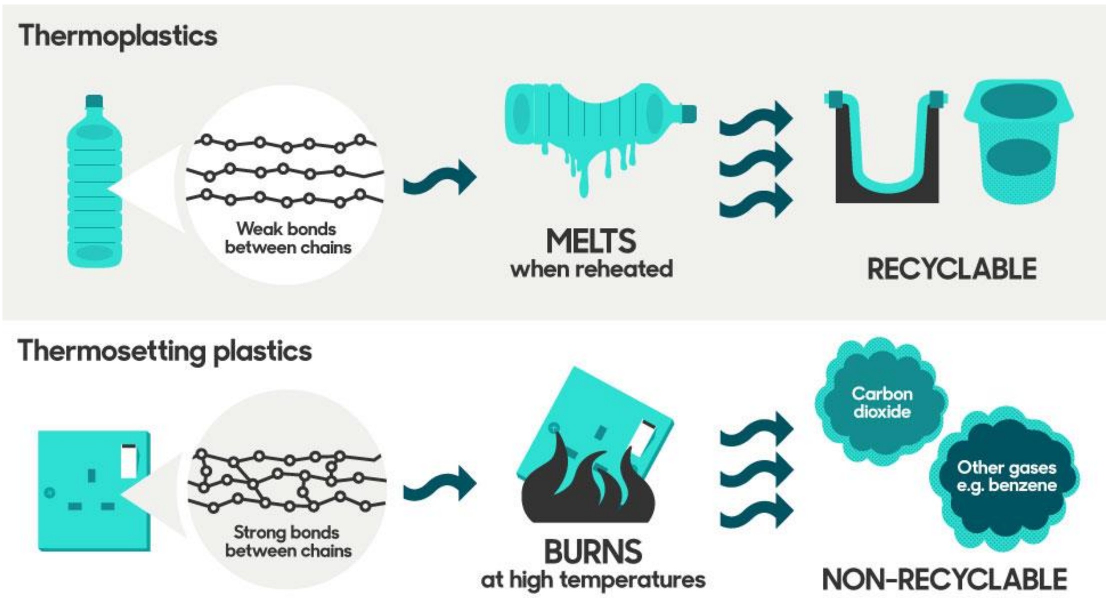
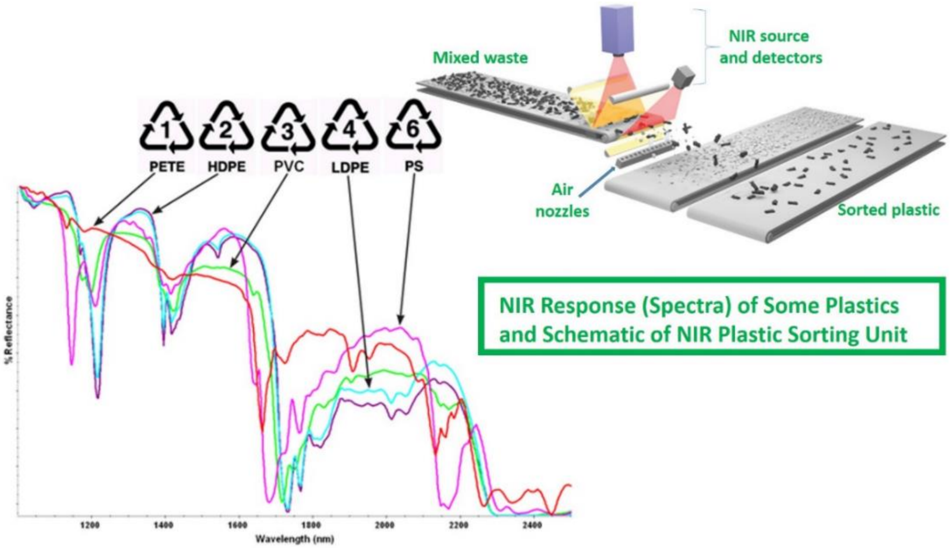


Fig.3.1 Plastic categories, Thermoplastic and Thermosetting plastics different behavior

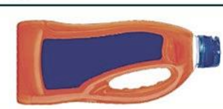
Process of Recycling Plastics

Plastic recycling is the process of recovering scrap or waste plastic and reprocessing the material into useful products. Since most of plastic is non-biodegradable, recycling is a part of global efforts to reduce plastic in the waste stream, especially the approximately eight million tons of waste plastic that enter the Earth's ocean every year. This helps to reduce the high rates of plastic pollution.
When different types of plastics are melted together, they tend to phase-separate, like oil and water, and set in these layers. The phase boundaries cause structural weakness in the resulting material, meaning that polymer blends are useful in only limited applications. The two most widely manufactured plastics, polypropylene and polyethylene behave this way, which limits their utility for recycling. Recently, the use of block copolymers as "molecular stitches" or "macromolecular welding flux" has been proposed to overcome the difficulties associated with phase separation during recycling.
Before recycling, most plastics are sorted according to their resin type. In the past, plastic reclaimers used the resin identification code (RIC), a method of categorization of polymer types, which was developed by the Society of the Plastics Industry in 1988. Polyethylene terephthalate, commonly referred to as PET, for instance, has a resin code of 1. Most plastic reclaimers do not rely on the RIC now; they use automatic sort systems to identify the resin, ranging from manual sorting and picking of plastic materials to mechanized automation processes that involve shredding, sieving, separation by rates of density i.e. air, liquid, or magnetic, and complex spectrophotometric distribution technologies e.g. UV/VIS, NIR, Laser, etc. Some plastic products are also separated by color before they are recycled. The plastic recyclables are then shredded. These shredded

fragments then undergo processes to eliminate impurities like paper labels. This material is melted and often extruded into the form of pellets which are then used to manufacture other products.



Plastic Identification Code

Symbol	Description	
1 PETE	Clear tough plastic such as soft drink, juice and water bottles.	
2 HDPE	Common white or coloured plastic such as milk containers and shampoo bottles.	
3 V	Hard rigid clear plastic such as cordial bottles.	
4 LDPE	Soft flexible plastic e.g. squeezable bottles such as sauce bottles.	
5 PP	Hard but flexible plastic such as microwave ware, takeaway containers, some yoghurt/ ice cream/jam containers, hinged lunch boxes.	
6 PS	Rigid, brittle plastic such as small tubs and margarine/butter containers.	
7 OTHER	All other plastics, including acrylic and nylon. Examples include some sports drink bottles, sunglasses, large water cooler bottles.	

What is PET

Polyethylene terephthalate commonly abbreviated PET, PETE, or the obsolete PETP or PET-P, is the most common thermoplastic polymer resin of the polyester family and is used in fibers for clothing, containers for liquids and foods, thermoforming for manufacturing, and in combination with glass fiber for engineering resins. Bottles made of polyethylene terephthalate (PET, sometimes PETE) can be "recycled" to reuse the material out of which they are made and to reduce the amount of waste going into landfills. PET is semi porous and absorbs molecules of the food or beverage contained, and the residue is difficult to remove: Heating the plastic enough for sterilization would destroy it. Therefore, most recycled bottles are used to make lower grade products, such as carpets. To make a food grade plastic, the bottles need to be hydrolyzed down to monomers, which are purified and then re-polymerized to make new PET. In many countries, PET plastics are coded with the resin identification code number "1" inside the universal recycling symbol, usually located on the bottom of the container.

PET is used as a raw material for making packaging materials such as bottles and containers for packaging a wide range of food products and other consumer goods. Examples include soft drinks, alcoholic beverages, detergents, cosmetics, pharmaceutical products and edible oils. PET is one of the most common consumer plastics used. Polyethylene terephthalate can also be used as the main material in making water-resistant paper. Recently they are being used in additive manufacturing, by melting it and turning it into filaments that can be used in 3D-Printers.

What is HDPE

High-density polyethylene (HDPE) or polyethylene high-density (PEHD) is a polyethylene thermoplastic made from petroleum. It is sometimes called "alkathene" or "polythene" when used for pipes. With a high strength-to-density ratio, HDPE is used in the production of plastic bottles, corrosion-resistant piping, geomembranes, and plastic lumber. HDPE is commonly recycled and has the number "2" as its resin identification code. HDPE has an excellent resistance to most solvent, which makes it go to plastic type for detergents, cleaners, industrial chemicals, antifreeze and bleach, it is also used extensively for less harsh products like shampoo, conditioners, motor oil and soaps. Recycled HDPE is used to make pipe, buckets, flower pots, plastic lumber for decks and recycling bins.

What is RPVC

Polyvinyl chloride also known as polyvinyl or vinyl, commonly abbreviated PVC, is the world's third-most widely produced synthetic plastic polymer, after polyethylene and polypropylene. PVC comes in two basic forms: rigid (sometimes abbreviated as RPVC) and flexible. The rigid form of PVC is used in construction for pipe and in profile applications such as doors and windows. It is also used in making bottles, non-food packaging, and cards (such as bank or membership cards). It can be made softer and more flexible by the addition of plasticizers, the most widely used being phthalates. In this form, it is also used in plumbing, electrical cable insulation, imitation leather, flooring, signage, phonograph records, inflatable products, and many applications where it replaces rubber

What is LDPE

Low-density polyethylene (LDPE) is a thermoplastic made from the monomer ethylene. It was the first grade of polyethylene, produced in 1933 by Imperial Chemical Industries (ICI) using a high-pressure process via free radical polymerization. Its manufacture employs the same method today. The EPA estimates 5.7% of LDPE (recycling number 4) is recycled. Despite competition from more modern polymers, LDPE continues to be an important plastic grade. In 2013 the worldwide LDPE market reached a volume of about US$33 billion. LDPE Chemical Resistance:

- Excellent resistance (no chemical reaction) to alcohols, bases and esters
- Good resistance to aldehydes, ketones and vegetable oils
- Limited resistance to aliphatic and aromatic hydrocarbons, mineral oils, and oxidizing agents
- Poor resistance, and not recommended for use with halogenated hydrocarbons.

04 PE-LD

What is PP

Polypropylene (PP), also known as polyprotein, is a thermoplastic polymer used in a wide variety of applications. It is an addition polymer made via chain-growth polymerization from the monomer propylene. Polypropylene can be produced in a variety of structures giving rise to applications including packaging and labeling, textiles, plastic parts and reusable containers of various types, laboratory equipment, automotive components, and medical devices. It is a white, mechanically rugged material, and is resistant to many chemical solvents, bases and acids. As polypropylene is resistant to fatigue, most plastic living hinges, such as those on flip-top bottles, are made from this material. However, it is important to ensure that chain molecules are oriented across the hinge to maximize strength.

05 PP

Polypropylene is used in the manufacturing piping systems; both ones concerned with high-purity and ones designed for strength and rigidity (e.g. those intended for use in potable plumbing, hydronic heating and cooling, and reclaimed water).This material is often chosen for its resistance to corrosion and chemical leaching, its resilience against most forms of physical damage, including impact and freezing, its environmental benefits, and its ability to be joined by heat fusion rather than gluing. Many plastic items for medical or laboratory use can be made from polypropylene because it can withstand the heat in an autoclave. Its heat resistance also enables it to be used as the manufacturing material of consumer-grade kettles, Food containers made from it will not melt in the dishwasher, and do not melt during industrial hot filling processes. For this reason, most plastic tubs for dairy products are polypropylene sealed with aluminum foil (both heat-resistant materials)

What is PS

Polystyrene (PS) is a synthetic aromatic hydrocarbon polymer made from the monomer styrene. Polystyrene can be solid or foamed. General-purpose polystyrene is clear, hard, and rather brittle. It is an inexpensive resin per unit weight. It is a rather poor barrier to oxygen and water vapor and has a relatively low melting point. Polystyrene is one of the most widely used plastics, the scale of its production being several million tons per year. Polystyrene can be naturally transparent but can be colored with colorants. Uses include protective packaging (such as packing peanuts and CD and DVD cases), containers (such as "clamshells"), lids, bottles, trays, tumblers, disposable cutlery and in the making of models.

As a thermoplastic polymer, polystyrene is in a solid (glassy) state at room temperature but flows if heated above about 100 °C, its glass transition temperature. It becomes rigid again when cooled. This temperature behavior is exploited for extrusion (as in Styrofoam) and for molding and vacuum forming, since it can be cast into molds with fine detail.

Polystyrene (PS) is used for producing disposable plastic cutlery and dinnerware, CD "jewel" cases, smoke detector housings, license plate frames, plastic model assembly kits, and many other objects where a rigid, economical plastic is desired.

Advantages of Recycling Plastics

1. Provision of a Sustainable Source of Raw Materials
2. Reduces Environmental Problems
3. Reduces Landfill Problems
4. Consumes Less Energy
5. Encourages a Sustainable Lifestyle among People

Map of Recycling plastic:

Recycled filament and raw Products in market for AM Technology

B-pet is a company that utilizes PET plastic to create 3-D printing filament in different colors. Their product, shown below in Figure.2. 12, has no roundness deviation, 100% recyclable, and has the same properties as virgin PET but costs 70% less. The price is about 35 dollars for a spool 1.75 mm diameter filament. The filament comes in multiple different colors. While B-pet creates filament with 100% recycled material, it does not fully solve the problem statement because it is not dealing directly with the fact that many of these developing countries have an issue with too much PET plastic waste. Improvements could be made to the work that B-pet does by focusing solely on PET plastic waste, which would make it very applicable and useful to areas with excess waste. While the filament that B-pet produces works well with 3-D printers, its application outside of the 3-D printing field is limited. This brings up another potential improvement that can be made on B-pets product.

Fig.3. 3: B-PET recycled plastic 3-D printer filament [10]. Image reproduced without permission from David Perez.

- B-Pet is a stiff and very lightweight material, which makes it very strong and impact-resistant. It's a stable and harmless plastic, because of its vapor barrier and strength properties.

- B-Pet is 100% recyclable. No burning petroleum is needed for its fabrication process, and it quits bottle waste from environment.

- B-PET has the same properties as virgin PET but it costs 70% less. And it has other special features like flexible strength, easy adhesion, consistent diameter and no bubbles, among others.

Refil: At present, most plastic waste is perceived as valueless, it ends up in landfills or incinerators. Only a small fraction of the plastic waste is recycled. Unfortunately, a lot of discarded plastic ends up in the rivers, the sea (so called “plastic soup”), forests and even in animals. Plastic waste is a global problem and is interfering with the food chain and ecosystem. Moreover, plastic is made from oil, and this resource isn’t infinitely available. In this company they want to take responsibility and make smarter use of resources. They aim to offer the makers of the world a 3d printer filament that is fully recycled, with a quality that is comparable or exceeds premium non-recycled filaments. After years of extensive testing and fine-tuning they claim that they have produced fully recycled ABS filament made from car dashboards and PET filament made from old PET bottles.

This Recycled PET filament is made from old PET bottles. It is up to 90% recycled. It's strong, flexible and almost no warping during printing.

Recycled PET filament is made from old PET bottles, it’s up to 90% recycled, After extensive testing and optimizing a premium quality is reached from recycled filament. It's strong, flexible and almost no warping during printing.

This Recycled PET filament is made from old Green PET bottles and it’s up to 90% recycled. After extensive testing and optimizing a premium quality recycled filament have been created.

Trash Lab: For thousands of years, trash has been discriminated against, labeled as waste, worthy only of disposal. But Miniwiz they see opportunity and possibilityin trash. The possibility of a circular and sustainable economy and a cleaner, brighter future for us and the generations to follow - but only if we learn how to work with it, rather than discard it. And in order to learn, first, we must get to know it, and intimately. Miniwiz scientists and engineers have invented over 1000 new and entirely sustainable materials and applications. Miniwiz invents 20 new materials every month using the world's richest resource - trash. With daily experiment in the Trash Lab to build updated material portfolio, a vast collection with unlimited possibilities of scaled application, at an even higher performance than the traditional carbon-heavy materials currently deployed in global system.

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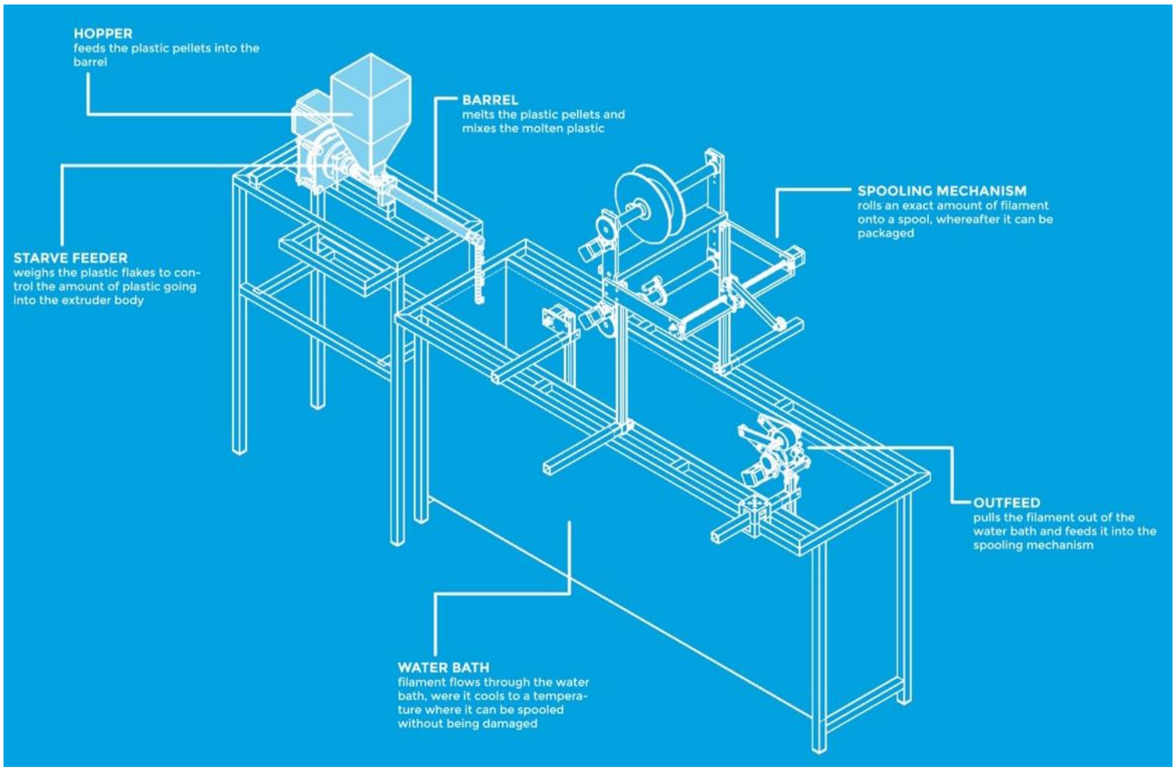
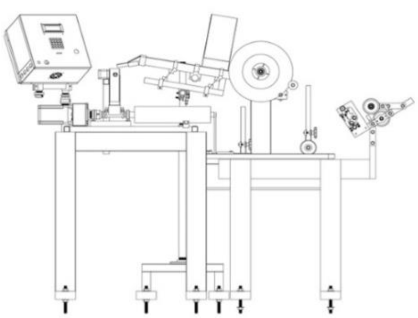
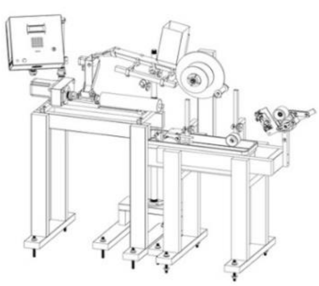
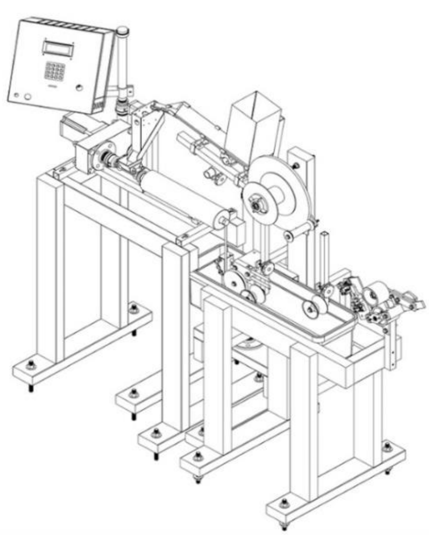
Natrilon™ is a revolutionary yarn technology, made from 100% Post-Consumer recycled PET beverage bottles and enhanced with high-performance Nano SiO2 from rice husks. Amorphous high-surface area Nano SiO2 is distilled from rice husk via a proprietary Miniwiz process along with Far Eastern New Century Innovation. The filaments can be circular, triangular or hexagonal in the cross-sectional structure which in turn, means Natrilon™ can be created with multiple optical outcomes. In regards to handle, Natrilon™ Circular cross-section fiber gives you a merino wool texture, whilst triangular cross-section fiber delivers a silky satin-like sheen.Performance wise, Natrilon™ is very strong, durable and abrasion resistant whilst maintaining breathability. It is also rich in deodorizing qualities and is light reflective resulting in a lasting color retention. Custom colors are available in a minimum quantity order.

Reflow: It’s revolutionizing design and production in every field of endeavor from robotics, to consumer goods, right down to the objects in our homes. By combining this innovative technology with sustainable materials, we can create outstanding work together from the material we discard every day. Recycling is an essential human activity that we must recognize and value.









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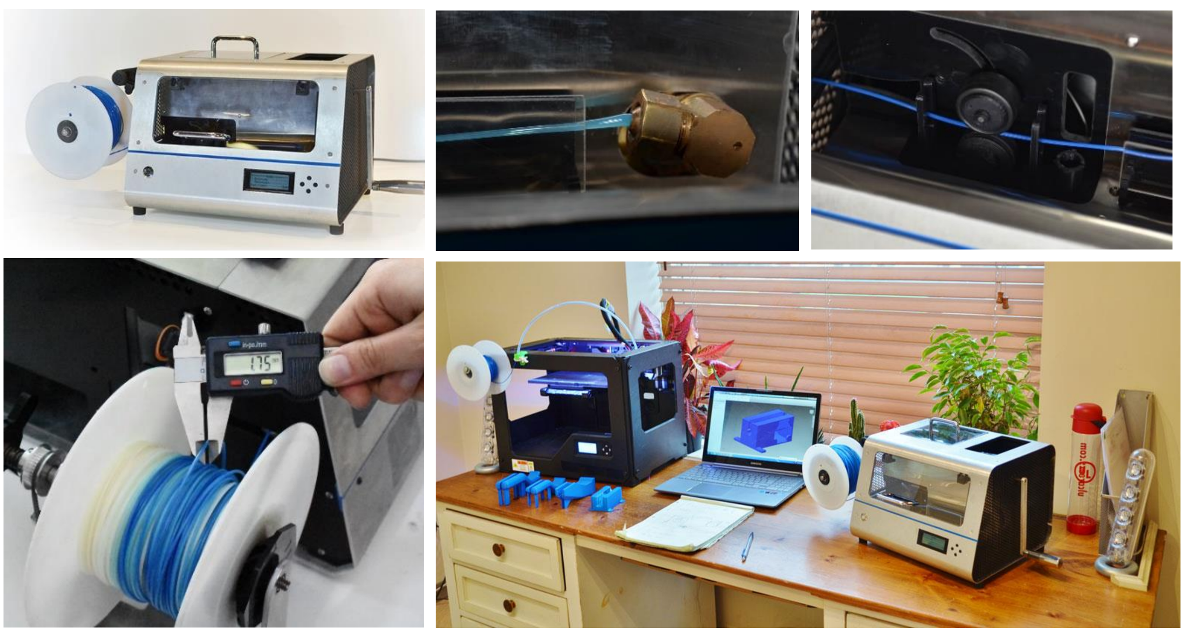
ReDeTec is a 3D printing company, founded to make 3D printing as accessible as possible. Their goal is that everyone have the opportunity to create whatever they wish, with no concerns for their wallet or the environment. The design technology available today is spurring a revolution in how people think, make, and create. Businesses and schools are increasingly turning towards 3D printing to maintain their competitive edge. With **Re**newable **De**sign **Tec**hnology, all that changes. Instead of racing to provide cheaper and cheaper alternatives, ReDeTec develops novel solutions to fundamentally improve the 3D printing experience at a fraction of the cost of traditional filament.

3D printing and recycling are a perfect match. Plastic waste is abundant, and 3D printers are one of the most accessible design tools available today. We allow you to recycle 3D printer waste into new filament, because this changes everything about 3D printing– instead of an industry driven by consumption, it becomes an industry driven by creation.

ProtoCycler is a revolutionary new product that allows users to recycle waste plastic into valuable 3D printer filament. It comes complete with a built-in grinder, distributed spooling, and intelligent computer control with real time diameter feedback. It's also fully UL safety certified, so users don't have to be worry about where it's used. With just the turn of a crank and push of a button, ProtoCycler automatically creates filament – safely, easily, and affordably. ProtoCycler creates ABS filament or PLA filament, so it can be used with any desktop 3D printer.



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Conclusion

In conclusion, Additive manufacturing technology has been used in engineering fields for many years in different scales, recently the technology has entered Architecture and product design, there has become incredible designs everyday with 3d-printing technology and it is becoming more and more friendly user and more people have the opportunity to use it worldwide, But on the other hand plastic pollution is one of the most severe environmental challenges that we face today, this project is attempting to use the PET bottles which has been started to restored in Dubai since 2017 as row material for filaments and using the existing technologies which are already invented and being sold to transfer the PET plastic bottle material into filaments for 3d printers in plant. In the next chapter the Design will be introduced, different concepts will be presented based on circle packing idea and the main challenge will be printing successfully and solution for junctions.

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Bottles
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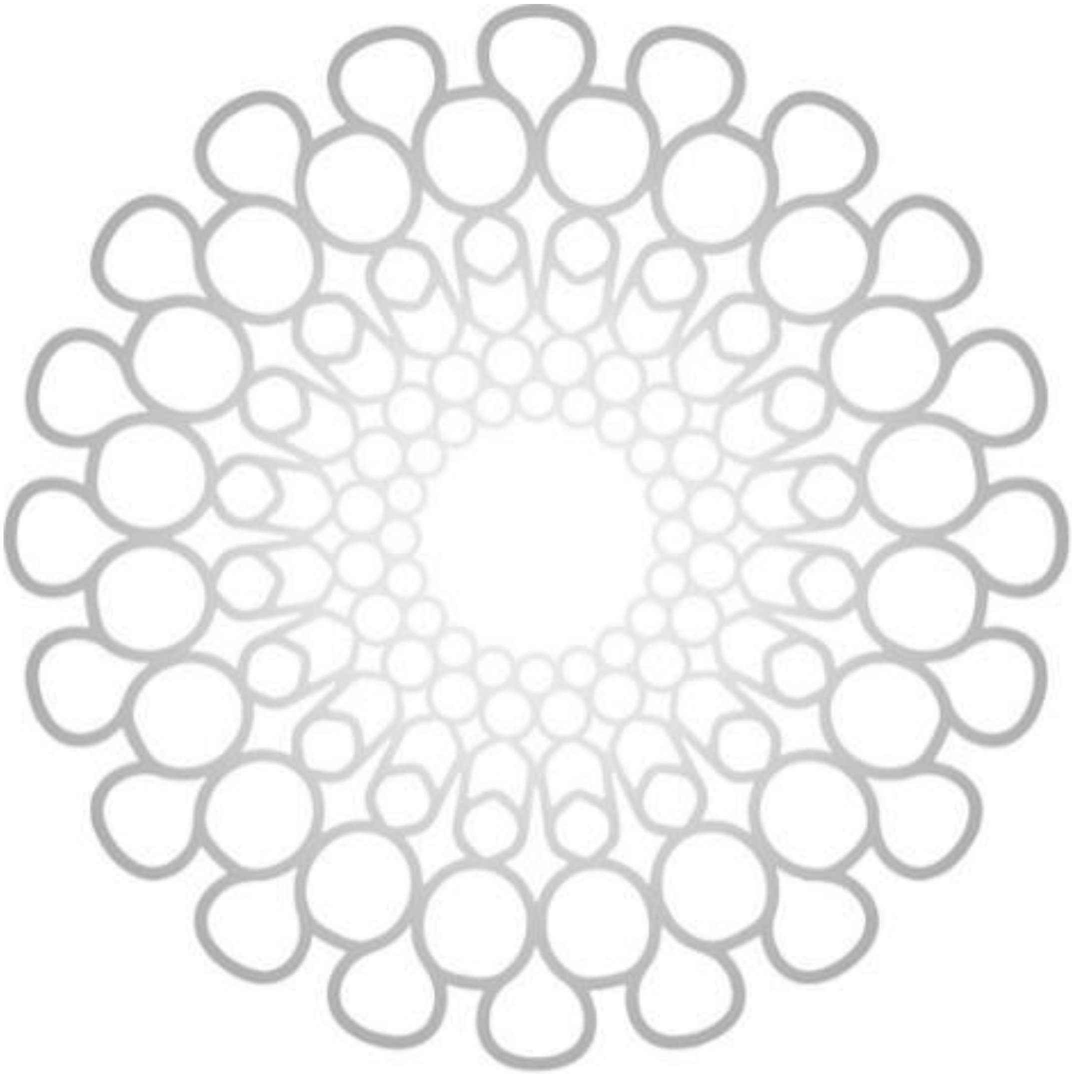

CHAPTER 4

The Process Of Design

This chapter is showing the experimental Design part with AM technology, a modular design which is inspired by circularity of the Logo of Expo 2020, will be practically studied to be bulilt with three different types of 3D-Printers: 0.7mm and 1.2 mm nozzle size WASP 3d-printer, and 3 mm nozzle size Delta 3MT WASP 3Dprinter, and also with using many different filaments and pellets mainly recycled PETEG filament provided by Filo alfa. In this chapter it will be shown that how the design has the ability to be printed, packed, transported and assembled and installed in the site by a very simplicity of junctions and portability is the main challenge in this design prototype, the result of the modeling will indicate and prove the feasibility of the design with Sustainable approach for using 3D Printing technology with Recycled Materials and future developments will be expected with these kinds of practical experiments.

Key-words: Expo, Mega Events, Logo, prototype, junction, connector, pyramid.

Expo Events

An Expo is a global event that aims at educating the public, sharing innovation, promoting progress and fostering cooperation. It is organized by a host country that invites other countries, companies, international organizations, the private sector, the civil society and the public to participate. Due to the diversity of its participants, from top decision makers to children, Expos offer a multifaceted event where extraordinary exhibition, diplomatic encounters, business meetings, public debates and live shows take place at the same time.

Expo DUBAI 2020

Dubai Expo theme will be a festival of human ingenuity. The engines of growth are no longer steam powered. Instead, collaboration and partnership have taken its place, becoming the driving force behind new developments. Expo 2020 will showcase and explore what is possible when new ideas and people connect. The theme will be Connecting Minds, Creating The Future, and the six months will see hundreds of companies and people from many countries getting together to discuss ideas and foster creativity.

Expo DUBAI 2020 LOGO

"The design of the logo is inspired by a civilisation that existed 4,000 years ago in an area extending from Baynounah in Abu Dhabi to Saroug Al Hadeed in Dubai and from Maliha Valley in Sharjah to the mountains of Ras Al Khaimah and Fujairah," [1]

The ring itself is made of pure gold and has small artistic designs around it, the ring and the circular shape which inspired the logo stand for seamless connnectivity, resilience and strength.

[1] http://www.arabianbusiness.com/dubai-s-new-expo-2020-logo-based-on-design-of-ancient-ring-626411.html

Organization

The main site of Expo Dubai 2020 will be a 438-hectare area (1083 acres) located midway between Dubai and Abu Dhabi. The master plan, designed by the American firm HOK, is organized around a central plaza, entitled Al Wasl (meaning "the connection" in Arabic language), enclosed by three large pavilions which will be built by Al-Futtaim Carillion, each one dedicated to a sub-theme. Dubai has also been emphasizing on investments in various sectors such as economic growth, real estate, environmental avenues and public affairs. In recent times, Dubai has made major investments in Real Estate as well as introduced a world's largest Solar Power Project which is all set to start by Expo 2020.

Apart from pumping money, the nation is also keen on giving equal prominence to public relationships. The initiative – Dubai Happiness Agenda, has 16 programs under four themes that sums up 82 projects to be set in the city with an aim to make the city the happiest by 2020. The Dubai Expo 2020 also would see a rise in the GDP as predicted by the International Monetary Fund.

A Sustainable Master Plan for Dubai Expo

With its mixture of education, innovation and entertainment, the plan reflects the wonderful qualities of Dubai and the form and spirit of a World Expo. The site is on the southwestern edge of Dubai in Jebel Ali, near Dubai's new Al Maktoum International Airport and Jebel Ali Port, the world's third-busiest port.

The design features three separate pavilions symbolizing opportunity, sustainability and mobility, with "innovation pods" and "best practice areas" in each thematic zone. These three zones emanate from a central plaza named the Al Wasl, the historic Arab name for Dubai meaning "the connection." Inspired by the layout of a traditional Arabic "souk," or marketplace, the design places larger pavilions to the perimeter while clustering smaller exhibit spaces toward the center of the site. This creates a smooth pedestrian flow while encouraging interaction among visitors.

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Barricade Design: First Alternative

The Design Started with taking the logo on Expo 2020 into consideration, the logo is consisted of a circular shape, in geometry there are many definitions about circles and their relations to each other, I started my Design considering Tangency of circles and their relations to each other, circle packing is the study of the arrangement of circles (of equal or varying sizes) on a given surface such that no overlapping occurs and so that all circles touch one another, according to this definition I created a circle packing in a circle with different diameters starting from the central circle and definite numbers of circles arraying polar around the central circle. The two parameters are the radius of the Central circle and the number of circles that we want to array around central circle in a way they are all tangent to each other. (Fig.4. 1 and Fig.4. 2)

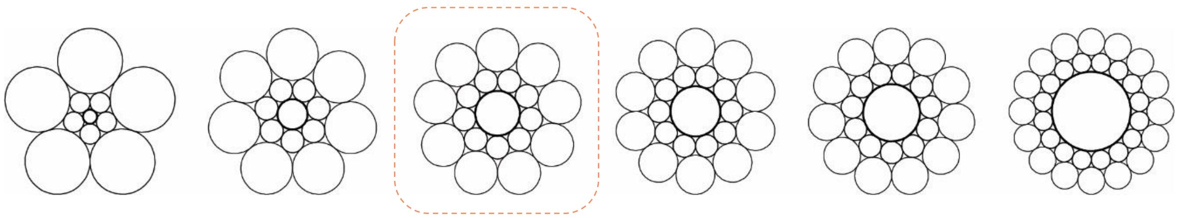


Fig.4. 1: Different Packing Options Based on central circle and numbers of Arrayed circles.

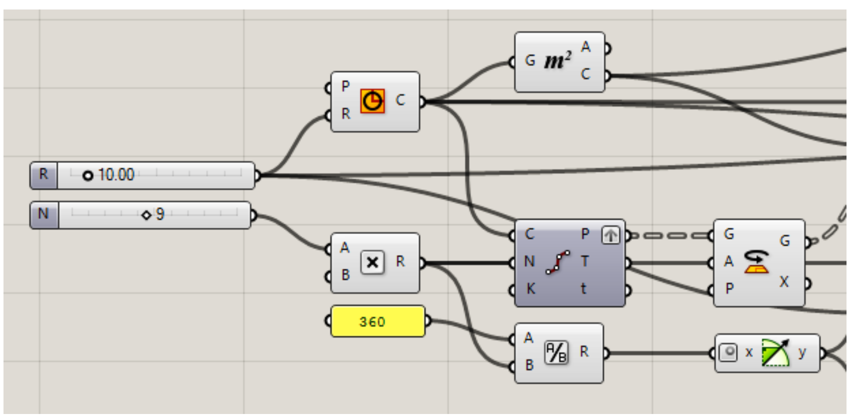
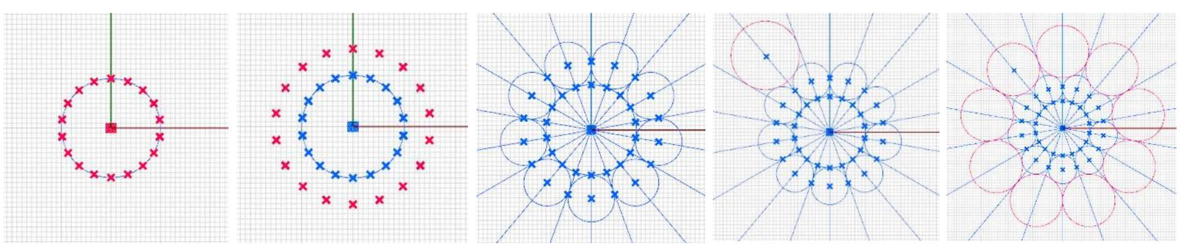


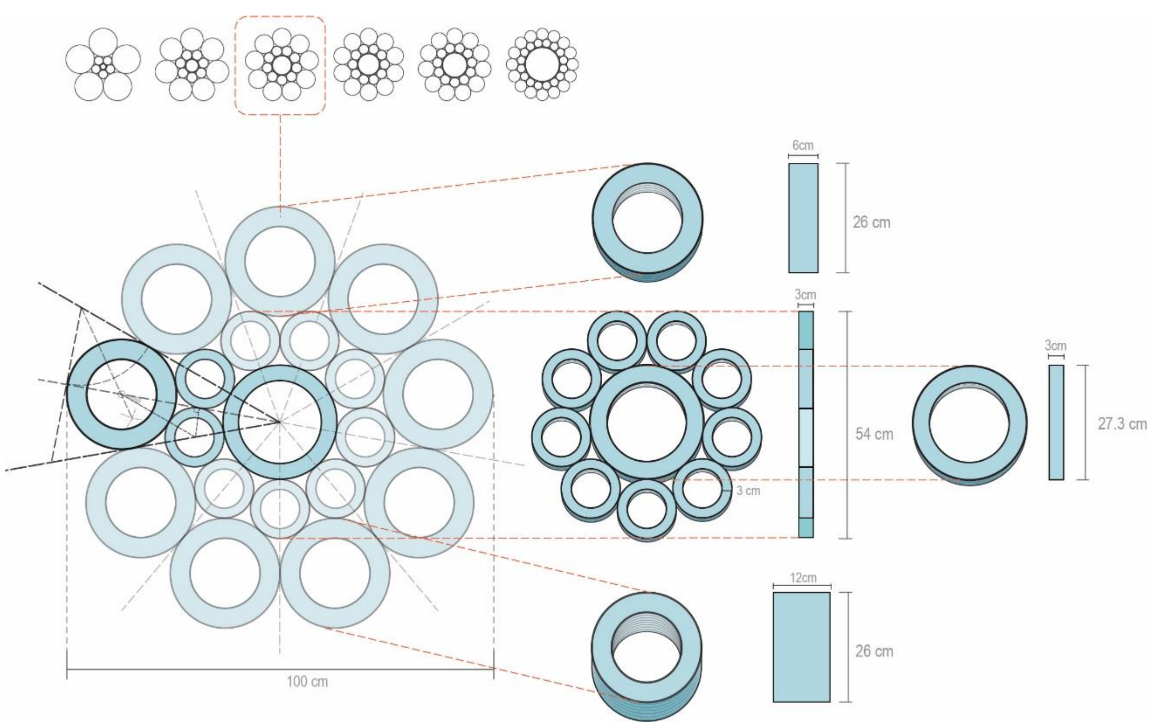
Fig.4. 2: Central circle Radius= 10 cm and number of circles surrounded tangent = 9



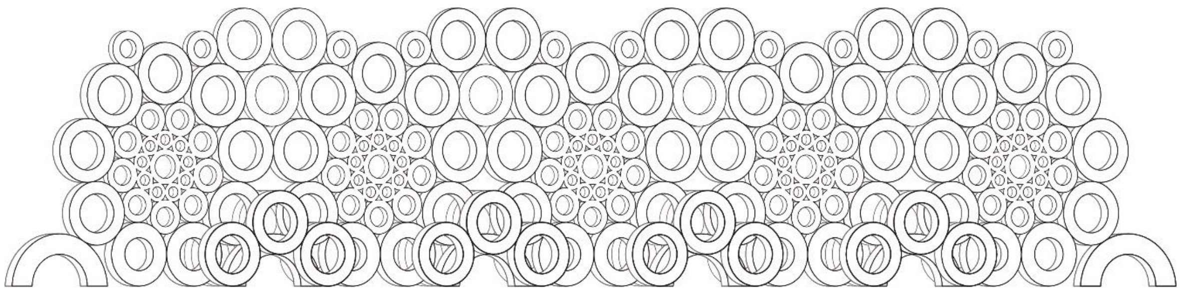
Design Objectives

The main Goal is to accomplish a project from the concept and design phase to build and execution phase using 3D-Ptinting technology, the concept response to the 3D-Printing challenges and limitations, the objective is to design a barricade for Expo as a Mega Event, the objective is to print elements and easily assembled in the site.

This approach features a bottom-up design process, composed of variable truncated cylinders, in which these basic constructive elements are filling the entire surface creating a network, all cylinder (circles) are in tangency with each other and they have no overlapping. The cylinders negotiate their parameters with each other by adapting their size, form and position. While maintaining their individual diversity and freedom, the elements cooperate to achieve common goals such as overall stability, shape, illumination, views and spatial quality as a barricade.



The experiment is intended to demonstrate how architects can use Recycled Material in Additive Manufacturing and 3D-Printers, it is possible on one side to overcome logistical and fabrication constraints with integrated solutions, like having a simple junction solution and separated labeled pieces and the other goal is to exploit the potential of digital design on the aesthetical level using 3D-Printers in Architecture for larger scales.

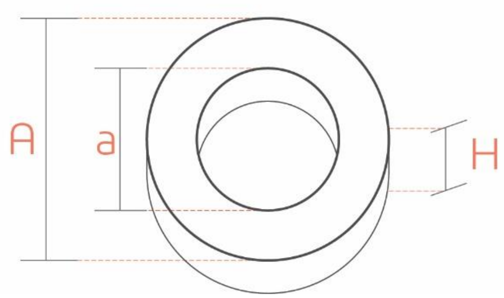


The Modules are designed to be printed and easily assembled and transported, the 3D-Printer is called FDM and the process starts with a string of solid material called the filament. This line of filament is guided from a reel attached to the 3D printer to a heated nozzle inside of the 3D printer that melts the material. Once in a melted state, the material can be extruded on a specific and predetermined path created by the software on the computer. As the material is extruded as a layer of the object on this path, it instantly cools down and solidifies – providing the foundation for the next layer of material until the entire object is manufactured.

Prototype:

The cylinders are manufactured two different 3d-printers and two different materials, in two different scales, one model is a 1:2 scale model using a Wasp 3D-Printer with a 1.2mm Nozzle size, using Recycled PETG Filaments provided by FiloAlfa Company, the other sample model is in 1:1 scale using Delat 3MT Wasp 3D-Printer with a 3mm Nozzle size, with this one we are using PLA Recycled Pellets. One Modul of the Structure is consisting of 20 Pieces that each of which are printed and labeled separately

C1	A:115 mm a: 60 mm H: 100 mm	B1	A:115 mm a: 70 mm H: 50 mm
C2	A: 115 mm a: 60 mm H: 100 mm	B2	A:115 mm a: 70 mm H: 50 mm
C3	A: 115 mm a: 70 mm H: 50 mm	S1	A: 65 mm a: 30 mm H: 30 mm
C4	A: 115 mm a: 70 mm H: 50 mm	S2	A: 65 mm a: 30 mm H: 30 mm
C5	A: 115 mm a: 70 mm H: 50 mm	H	A: 200 mm a: 115 mm H: 50 mm
C6	A: 115 mm a: 70 mm H: 30 mm	E1	A:115 mm a: 70 mm H: 30 mm
C7	A: 115 mm a: 70 mm H: 50 mm	E2	A:115 mm a: 70 mm H: 50 mm
C8	A: 115 mm a: 70 mm H: 50 mm	E3	A:115 mm a: 70 mm H: 50 mm
C9	A: 115 mm a: 70 mm H: 50 mm	P1	A:14 mm a: - H: 120 mm
CC	A: 500 mm a: 40 mm H: 30 mm	P2	A:10 mm a: - H: 150 mm



Pieces are connected by another cylinder element, as shown in two colors, the elements C6 and E1 and B1 and B2 have the possibility to rotate in their axis of junctions. The other elements are fixed in their place, the fixing is simply by filling the connector element into the two neighboring elements, the map of elements and connections is shown in Fig.4. 3 and Fig.4. 4, the junction detail is detailed in Fig.4. 5 and there is a base element to fix and stabilize the structure on the Floor, that is presented in Fig.4. 6.

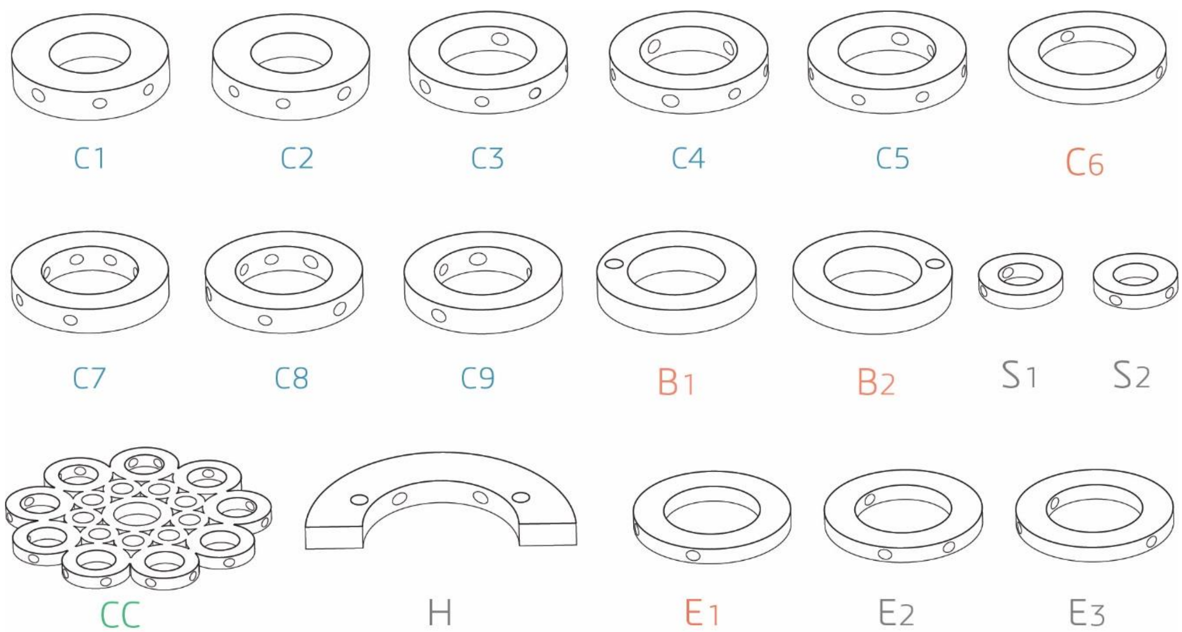


Fig.4. 3: The Element Label map

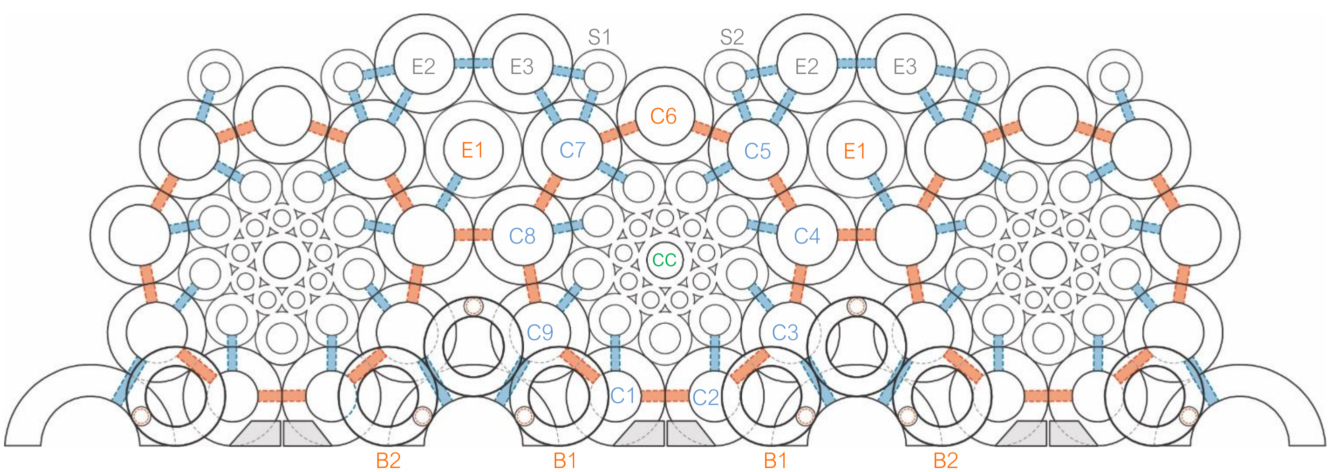


Fig.4. 4: The Connection Map

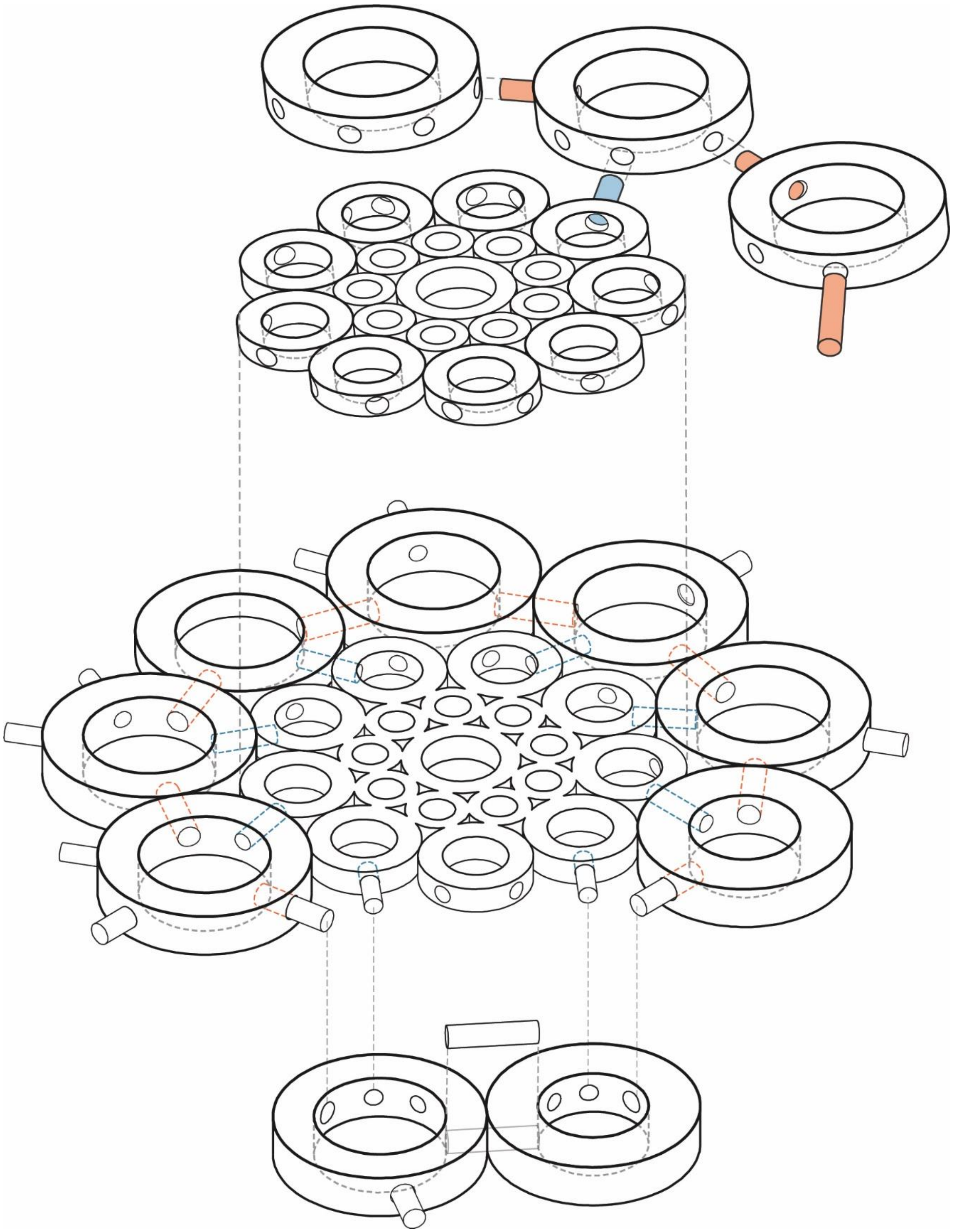


Fig.4. 5: The Elements Junction Detail

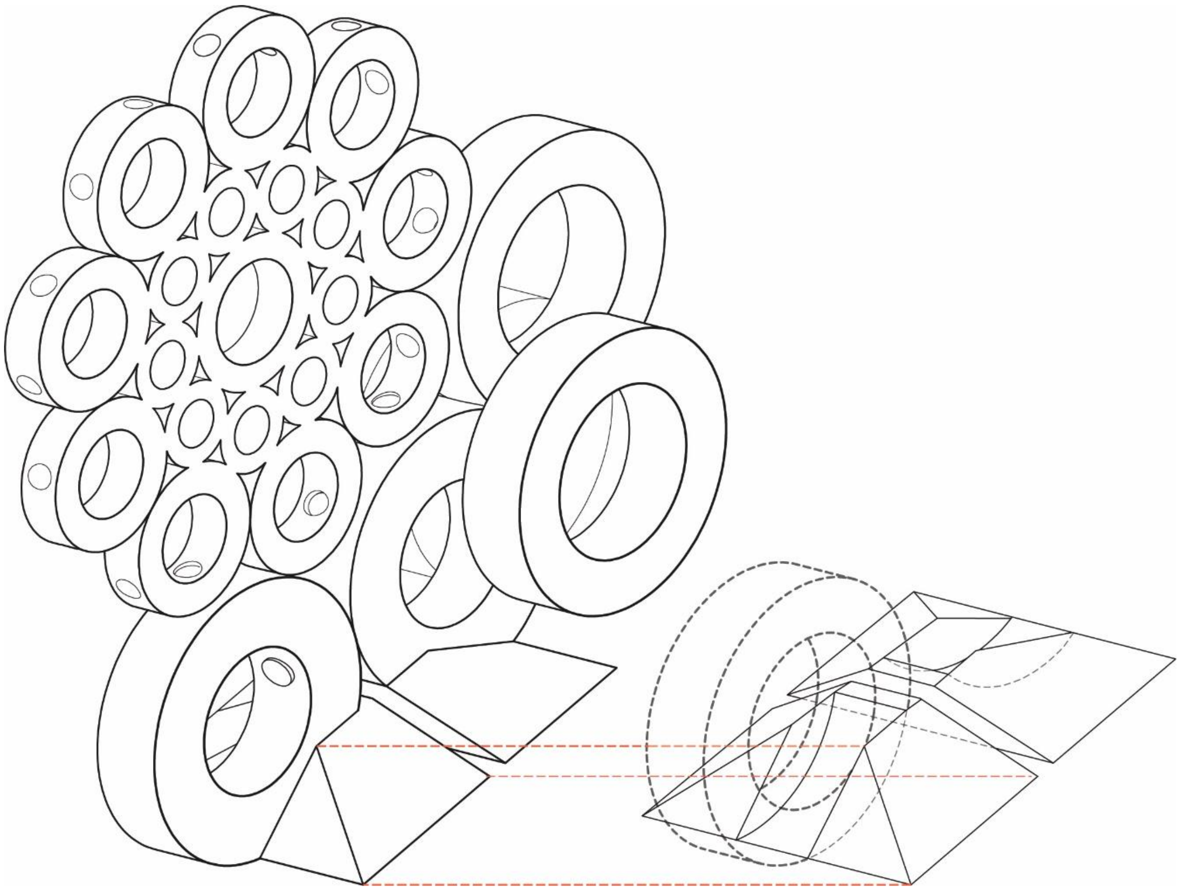
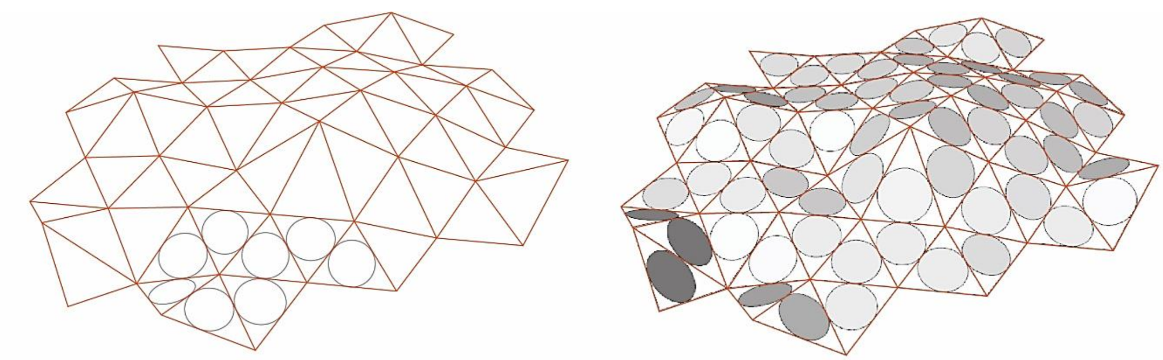


Fig.4. 6: The Base, Connection to the Floor illustration

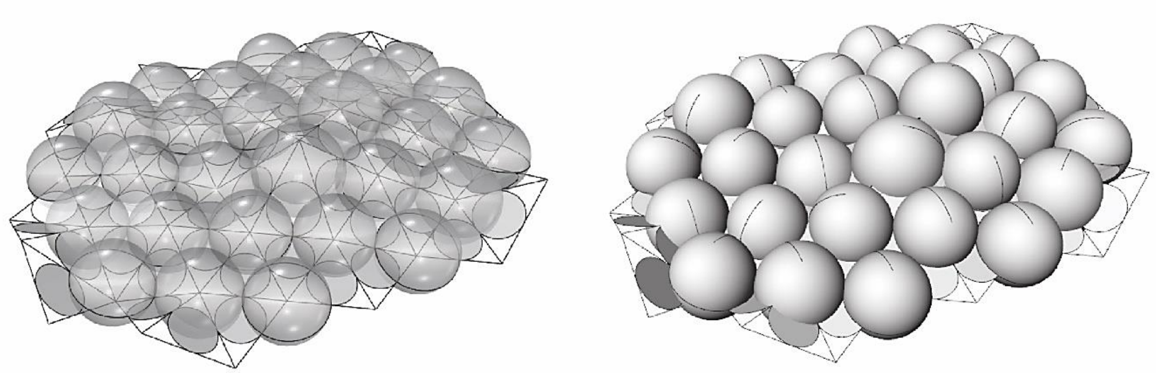
Barricade Design: Second Alternative

The Second Alternative is the use of circle packing is a surface and a mesh, For having circle packing arrangement on surfaces in We must study triangle meshes, where the incircles of the triangles form a packing, i.e., the incircles of two triangles with a common edge have the same contact point on that edge as shown below:

This is one of the many possible structures derived from a newly introduced type of triangle mesh, where the incircles of triangular faces form a packing. Such derived structures enjoy interesting properties relevant to both geometry and building construction.



A CP mesh is a triangle mesh whose incircles form a packing. Then spheres, which are centered at mesh vertices and are orthogonal to the incircles of neighboring triangles form a packing, too. Centers and axes of incircles define a hexagonal support structure with torsion-free nodes.



Design Concept

To come up with a concept I chose to choose a 3-dimensional solid geometry and arrange circles a tangent circle to the sides of a triangle in a pyramid, the pyramid is the base geometry in this design. The Process is shown in Fig.4. 7.

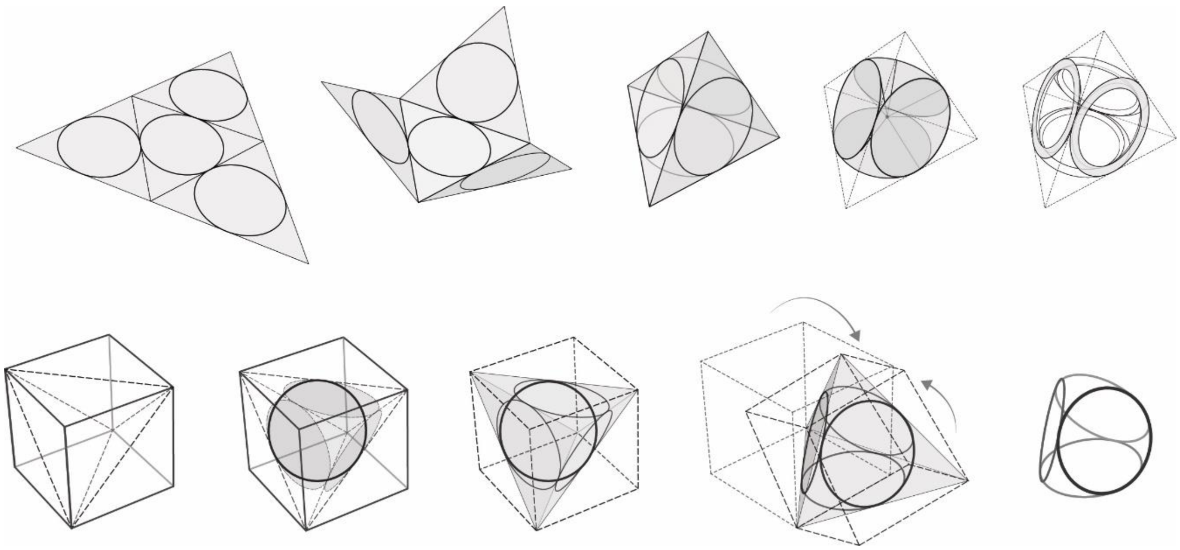
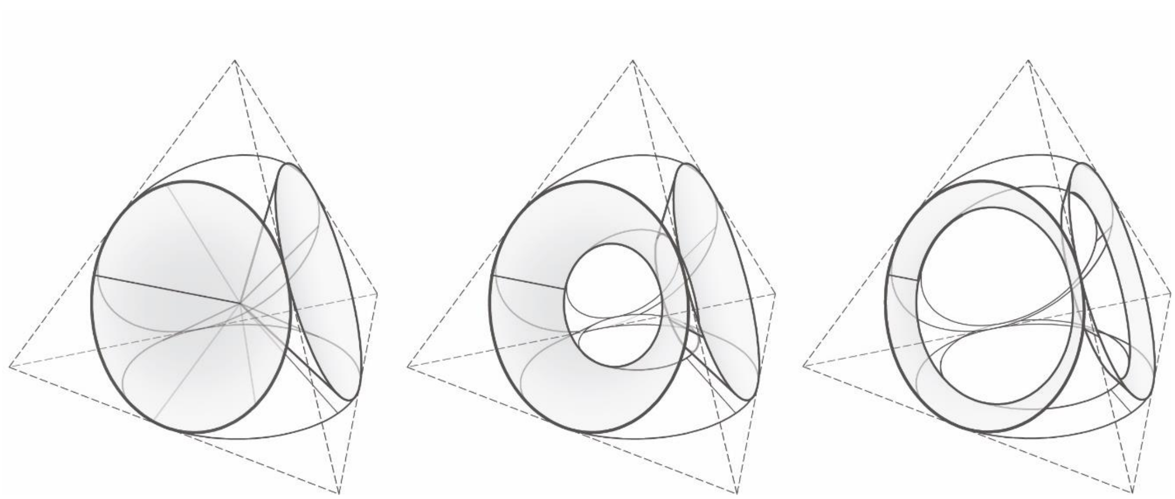


Fig.4. 7: The process of starting circle packing in a Solid geometry and how to achieve the geometry from a cube.



There are two options in printing this prototype, one is printing it as a whole, solid, union, and one other way is to print each element and piece separately and create a junction solution for it, in Fig.4. 8 one possible option for fixing pieces is demonstrated. This project is an experiment to study the feasibility and possibility of such design with AM technology.

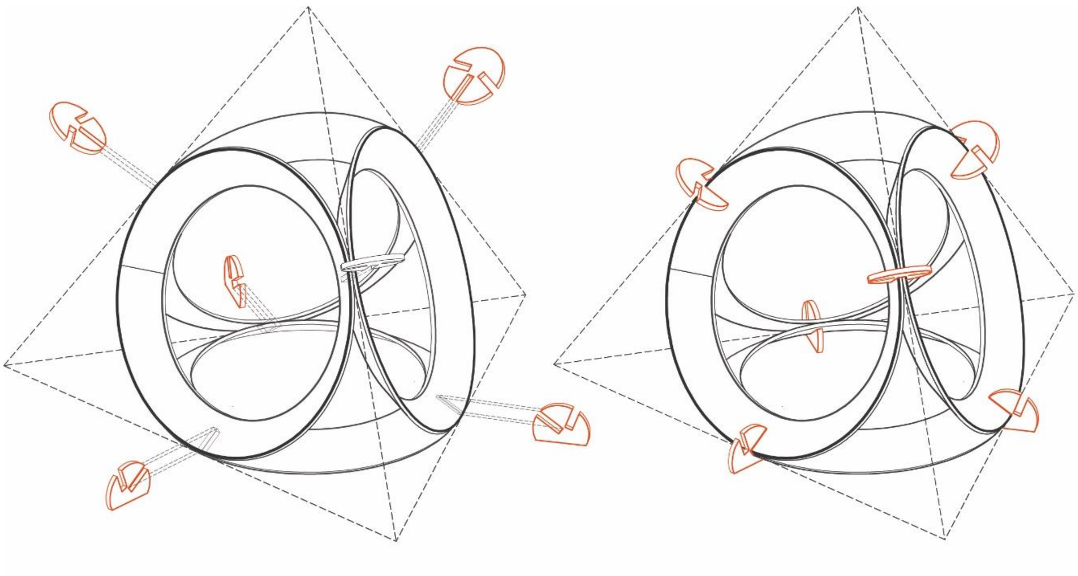
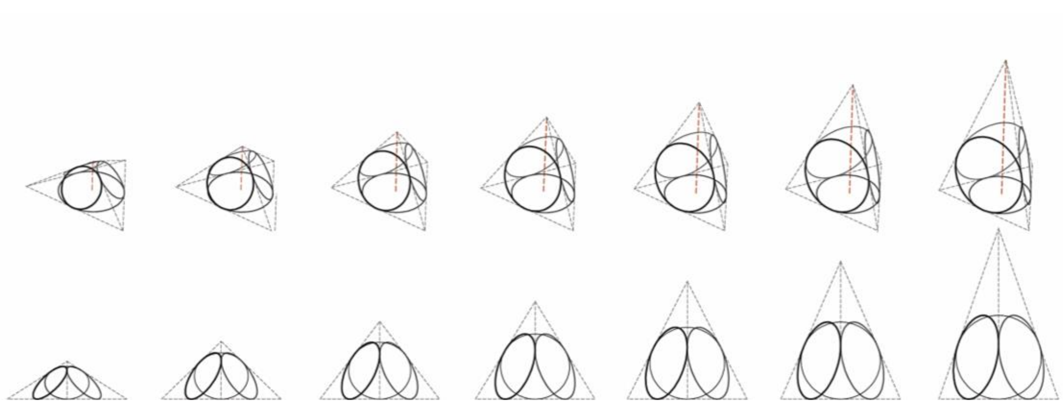
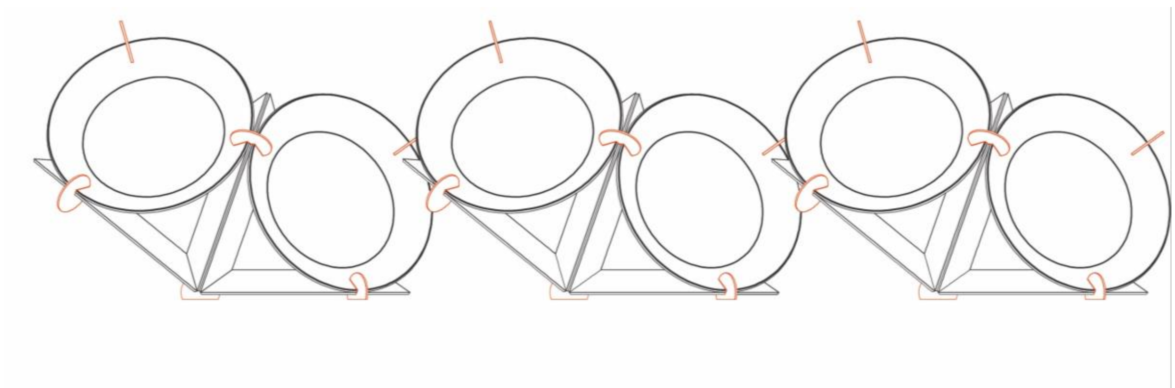


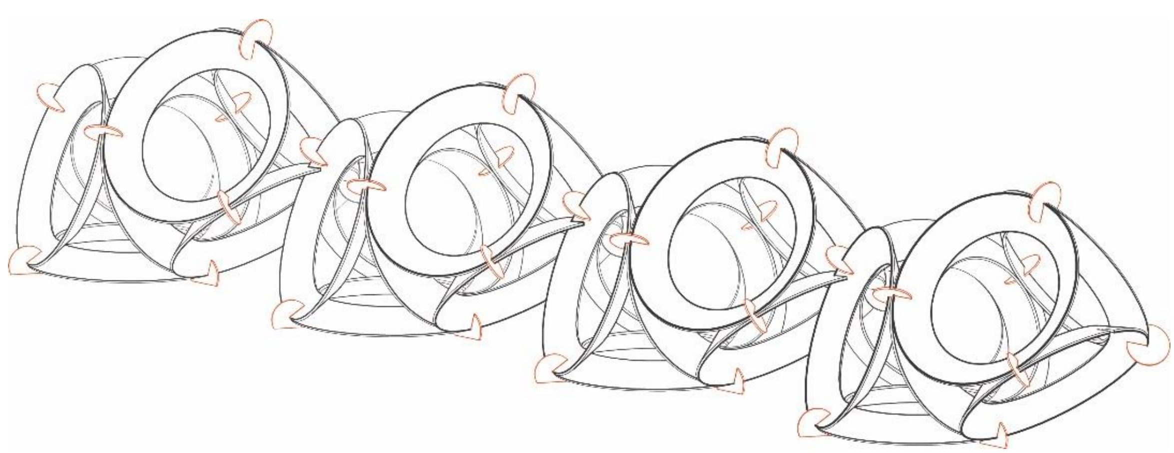
Fig.4. 8: The Junction Detail solution

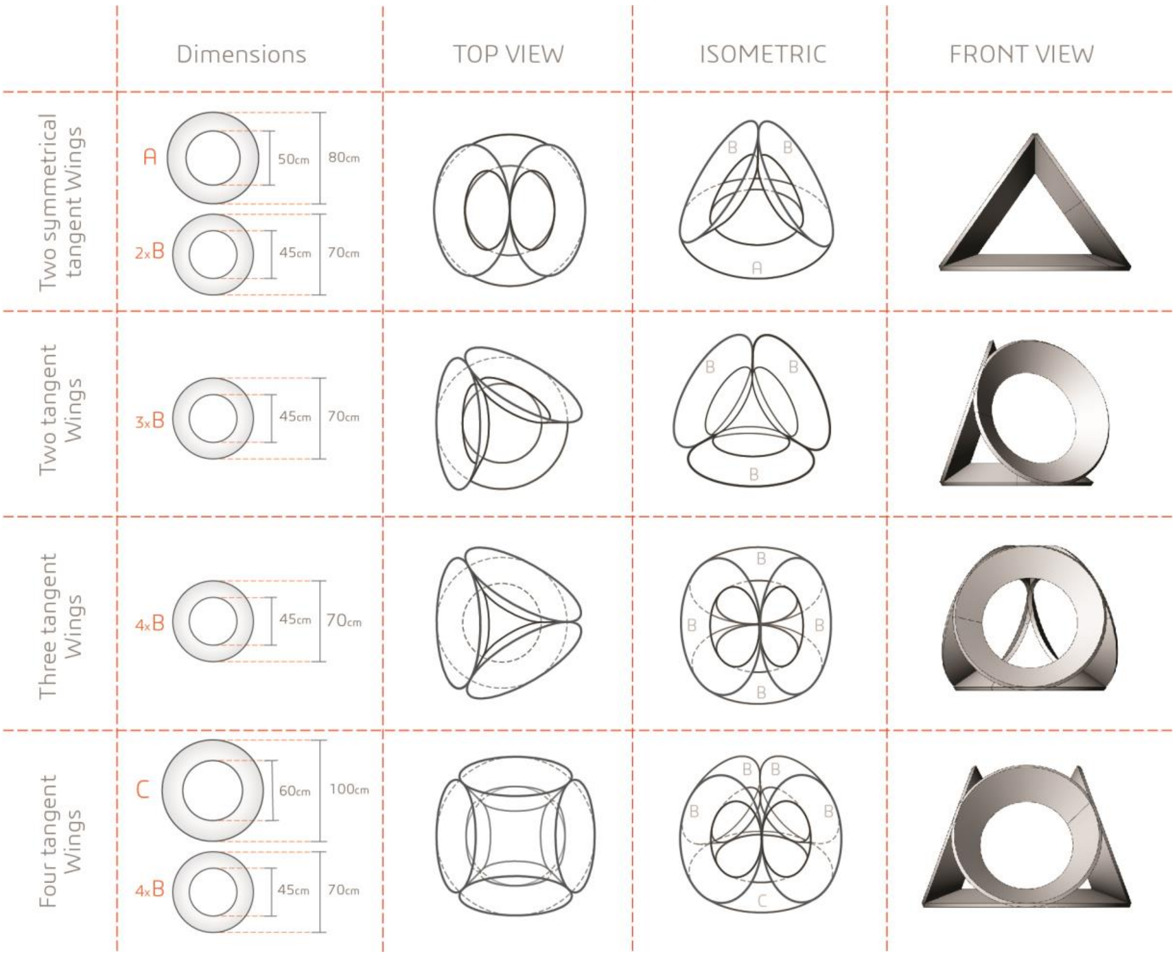


Top View



Isometric




Dimensions
TOP VIEW
ISOMETRIC
FRONT VIEW
Two symmetrical tangent Wings
A
50cm
80cm
2xB
45cm
70cm
B
B
A
Two tangent Wings
3xB
45cm
70cm
B
B
B
Three tangent Wings
4xB
45cm
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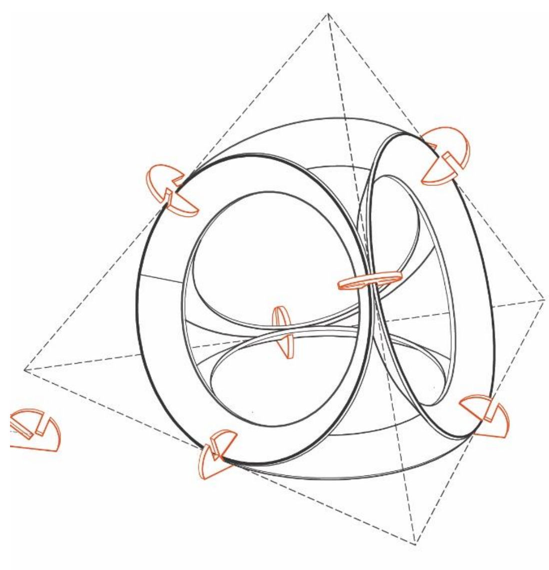
B
B
B
B
C



A report from the 3D-Printing Model

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