Contents

1.0 Introduction

2.0 History

3.0 Explanation of types
3.1 Fused Deposition Modelling
3.2 Selective Laser Sintering
3.3 3D Printing

4.0 Materials

5.0 Case Studies
5.1 Enrico Dini
5.2 Loughborough University
5.3 University of Southern California
5.4 Markus Kayser

6.0 Theory and Practice
6.1 Economics and Efficiencies
6.2 Transport and Logistics
6.3 Materials, Waste and the Environment
6.4 Structural Integrity
6.5 Design Possibilities

7.0 Potential Applications
7.1 Disaster Relief
7.2 Extraterrestrial Development

8.0 Conclusion

9.0 Bibliography and References
1.0 Introduction

Additive manufacturing or '3-D Printing' has emerged in the last 3 years as a genuine game changer in architectural technology. Using methods initially developed in the printing industry and later adopted by industrial designers for rapid prototyping, additive manufacturing has the potential to be scaled up and impact the sometimes stagnant technological advances in architecture and construction. Construction methods have changed little in the last 50 years. This has, in turn, greatly influenced architecture in terms of style and ambition. With the advent of advanced computer modelling and computer aided design, architects have started to dream up amazing forms and ambitious uses of technology but have found themselves restricted by the slow changes made in construction methods. Organic architecture and biomimicry leads to high costs and high levels of construction expertise. Advances in 3-D Printing may break down these barriers and enable cost effective implementation and freedom of design for architects. Another benefit may be found in disaster relief and cheap housing for an ever increasing global population. University of Southern California and Loughborough University have made great strides towards rapid additive manufacturing of usable building components with a view to printing entire buildings in the near future. The environmental impact of on-site 3-D Printing could contribute to huge reductions in the energy consumption of the construction industry. The European Space Agency and N.A.S.A. are both interested in its potential to build a base on the moon. Our Architectural Technology Research paper hopes to explain the history of this emerging technology, how it works, who the main innovators currently working in this field are, and how it might change our built environment in the future. We hope it will form an important part of the MArch knowledge based resource and help others understand the potential of this exciting new technology.

‘Famously, groups like Archigram proposed using construction cranes as permanent parts of their buildings. The crane could thus lift new modular rooms into place, add whole new floors to the perpetually incomplete structure, and otherwise act as a kind of functional ornament. The crane, “now considered part of the architectural ensemble,” Archigram’s Mike Webb wrote, would simply be embedded there, “lifting up and moving building components so as to alter the plan configuration, or replacing parts that had work out with a ‘better’ product. But 3D printers are the new cranes. For instance, what if Enrico Dini’s sandstone-printing device could be installed somewhere at the heart of a building complex—or up on the roof, or ringed around the edge of a site—where it could left alone to print new rooms and corridors into existence............”

Geoff Manaugh - BLDBLOG

Image from Plug-In City by Archigram
Warren Chalk, Peter Cook, Dennis Crompton
**Stereolithography**

The term "stereolithography" was coined in 1986 by Charles (Chuck) W. Hull. Stereolithography was defined as a method and apparatus for making solid objects by successively "printing" thin layers of the ultraviolet curable material one on top of the other. Hull described a concentrated beam of ultraviolet light focused onto the surface of a vat filled with liquid photopolymer. The light beam draws the object onto the surface of the liquid layer by layer, causing polymerization or crosslinking to give a solid. Because of the complexity of the process, it must be computer-controlled. In 1986 Chuck Hull founded the first company to generalize and commercialize this procedure, 3D Systems Inc. which is currently based in Rock Hill, SC. More recently, attempts have been made at constructing mathematical models of the stereolithography process, and designing algorithms that will automatically determine whether or not a proposed object may be constructed by this process.

---

**Selective Laser Sintering**

SLS was developed and patented by Dr. Carl Deckard at the University of Texas at Austin in the mid-1980s, under sponsorship of DARPA. A similar process was patented without being commercialized by R.F. Housholder in 1979.

Chuck Hull founded 3D Systems and developed the first commercial 3D Printing machine, it was called as Stereolithography Apparatus.

Fused deposition modeling (FDM) is an additive manufacturing technology commonly used for modeling, prototyping, and production applications. The technology was developed by S. Scott Crump in the late 1980s and was commercialized in 1990.
The term "3D Printer" was first used to refer rapid prototyping machines.

Enrico Dini invents his D-Shape printer, capable of printing 10m x 10m x 10m.

The world's first 3D printed aircraft created by Engineers at the University of Southampton.

1996
- M.I.T. develop inkjet printing
- Frescography

1998
- Z Corporation announced the introduction of the Spectrum Z510 3D Printing System, the first high-definition color 3D printer on the market.

2005
- Loughborough University develop the world's first concrete printer and announce plans to print a full structure by 2012.

2008
- Markus Kayser invents and successfully tests his 3-D printer in the Sahara desert. It uses only sand and sun.
3.0 Explanation of Types

3.1 F.D.M. - Fused Deposition Modelling

F.D.M. is most commonly used for fast prototyping, such as the example we have in the Edinburgh University workshop. It is the least complicated type of the three, as it uses heat rather than lasers to augment the state of the material being used. F.D.M.’s produce two materials; one disposable, used to support the structures, and the other material for the model.

Using F.D.M. gives a variety of material choices. Thermoplastics are the most common. As the material passes through the dispenser nozzle, heat liquefies the material. The dispenser nozzle can move in 3 dimensions, meaning the structure being printed can remain stationary. After the material has been dispensed it returns to its solid state, now bound to any surrounding material. The supporting structure can easy be removed, using an acid solution which does not damage the structure. William Palm (May 1998)

3.2 S.L.S. - Selective Laser Sintering

Like F.D.M., S.L.S. is also an additive process of gradually adding layer to layer to build the desired tree-dimensional shape. However, S.L.S. uses a high power laser to augment the state of materials. S.L.S. can fuse/print materials such as plastic, metal, ceramic and glass.

The process requires software to slice through the digital 3D object, producing cross sections. When the object is fully sectioned the printing can begin. It begins by a layer of the material in powder form being laid out. The laser then melts/fuses the appropriate cross section. The lasered powder becomes solid, and a new layer of powder is placed on top. This process is repeated until the object is formed.

S.L.S. has the widest range of available materials. The process also allows for multiple elements to be printed within one powder bed, resulting in high efficiency rates.

Unlike stereolithography and F.D.M., S.L.S. does not need to produce temporary structures as the object is constantly surrounded by unsintered powder. Prasad (2005)

3.3 3D Printing

Recently 3D Printing has become an umbrella term for all types of three-dimensional object manufacturing. However, it was first widely used after the invention of a three-dimensional manufacturing device that used the same type dispensing head as inkjet printer. This is a similar design to the S.L.S., in terms of a powder bed being altered, however 3D Printing does not use a laser, but instead an inkjet head passes over the bed and deposits a binder material in the same manner ink is printed on paper. It is relatively fast, and unlike all other types, allows for high definition colour to be used, resulting in a coloured final three-dimensional shape.

Alternative Methods

There are several other methods available for 3D printing, such as liquid 3D printing, however these, as yet, have not been considered for the building industry because of their unsuitability. Lilli Manolis Sherman (2004)
4.0 Materials

Concrete
This wall was created using a FDM style 3D printer at Loughborough University with the help of Foster and Partners and Buro Happold.

Metal
This sculpture by Bathsheba Grossman used SLS to create an intricate piece. It would not be possible using conventional metal crafting. It illustrates cladding possibilities.

Ceramic Brick
Created by Rael San Fratello Architects, this piece was an example of mass-customisation, rather than mass production. Indefinite designs can be produced without the need for retooling. [1]

Plastic
Using 3DP, University of Southampton’s Computational Engineering and Design Research team made a working drone/aeroplane which required no tools for its assembly. The printed body is made from nylon. It is very light, yet strong enough to fly at 100mph.

Stone
Designed by London based architect Andrea Morgante, and built by Engineer Enrico Dini’s printer, the Radiolaria Pavilion is a two meter tall monolithic sandstone structure printed using approximately 200 -10mm thick layers of sandstone rejects, aggregated by a new revolutionary inorganic binder.

Glass
Markus Kayser has created a solar powered SLS/FDM hybrid printer. It utilises the heat of the sun, using lenses, to alter sand into glass. The mechanism can fit into a large suitcase. This can also be done using a conventional SLS system.
Enrico Dini is an Italian civil engineer and inventor, based in Pisa, who founded D-Shape in 2008. He has developed a type of 3-D Printing using sandstone sand and inorganic resin. His initial patent used an epoxy resin but due to its binding properties he developed his own material cutting down on maintenance. The single armature machine is attached to a frame supported by four columns. The printer uses CAD files to print any 3-d shape and Dini claims the finished product is as strong as reinforced concrete. A layer of sandstone sand (any sand will work) is laid as per the Selective Laser Sintering method but instead of firing the layer with a laser, over 100 nozzles spray a 5mm layer of glue that hardens to 10mm thick binding the sand into a stone in the process. Because of the single armature design the D-Shape printer can print to 25 DPI. Both Hadid and Foster are in talks to use the printer. Dini has also been commissioned to use the machine to construct a pavilion on a roundabout in Pontadera, Italy. The pavilion mimics a biomorphic eggshell of marine protozoa that produce intricate mineral skeletons. The shape was developed by the architect Andrea Morgante (Future Systems). To achieve a similar shape using traditional construction methods would be very expensive. Enrico has entered into a contract including a consortium of Norman Foster, the European Space Agency and NASA among others to develop a way of using D-Shape technology to print a base on the moon. Enrico is also trying to convince the group responsible for the completion of Sagrada Familia in Barcelona to use his printer to finish the cathedral.

Advantages of D-Shape technology Vs traditional methods
D-Shape offers absolute advantages in terms of:

Quality: D-Shape allows more advanced design and construction. The actual building will correspond to the CAD design to within planned tolerances of 5-10 millimetres. The type and complexity of the architectural styles (be it rationalist, neoclassical, organic, etc.) will not impact on building cost. In fact, as the system does not require moulds for concrete casting, any feature conceived by the designer can be easily printed.

Quantity/Time: The system is estimated to be four times faster than traditional building methods. Furthermore, the required operating time is known in advance allowing accurate planning for the machinery and for resources. The annual production capacity of the first (smaller) model of D-Shape will be of 2500 m², which is equivalent to twelve two floor buildings.

Costs: despite the higher cost of the binder compared to Portland cement, the realization costs of D-Shape structures are 30%-50% lower than manual methods.

Safety: no human intervention means substantially reduced risk of accidents. The building industry is affected by a higher incidence of injuries and mortal accidents than many other industries. Severe and expensive safety measures must be constantly applied on the yard during building construction. D-Shape would lower the costs in terms of both human lives and financially. Enrico Dini (2011)
Loughborough University Civil and Building Engineering department have been running the Freeform Construction project since 2008. They have developed a 3D printing system using a special type of concrete to produce building components of up to 2m x 2.5m x 5m. They have developed their printer using the Fused Deposition Modelling system. It is essentially printing out an already wet mix of concrete. So far they have manufactured a 1 tonne reinforced concrete architectural piece has been produced to demonstrate the potential of the process and is the first in a series of components to be manufactured. Modern Architecture is demanding more and more from the design of buildings and we are now reaching a point where these designs cannot be realised using current state-of-the-art construction technologies. New developments in construction manufacturing technology are needed. Additive manufacturing techniques are able to build physical objects directly from computer generated instructions, which means that you can create complicated shapes that cannot be manufactured by conventional processes. The machines that translate the coded instructions into a real object produce quite small components and are often used for prototyping new products as part of the design process. These machines can be used to solve some of the complexity issues found in construction if they can be scaled up to produce massive parts out of appropriate material. Concrete Printing is one such process and uses a type of concrete that is deposited very precisely under computer control.
5.0 Case Studies

5.4 University of Southern California

The University of Southern California with funding from Caterpillar, NASA and the U.S. Army have developed a Fused Deposition Modelling printer that they hope to use to print a whole building in 24 hours in 2012. They hope to reduce waste, risk of injury, cost and environmental impact. Dr. Behrokh Khoshnevis, a Professor at S.U.C. created the fabrication company Contour Crafting, through the research at S.U.C. As well as housing they are also working with NASA on developing a system that might print a base on the moon. Like Loughborough University, their system prints in a concrete like wet mix, depositing layer upon layer. The Contour Crafting process creates an in situ pour, or print, with a far superior finish to conventionally cast concrete, with no loss in finish when casting complex curves and shapes.
5.0 Case Studies

5.5 Markus Kayser

Markus Kayser is an industrial designer based in London. He has developed a type of Selective Laser Sintering using the power of the sun instead of a laser. He has developed and tested a machine called the Solar Sinter. Using a series of lenses the printer lays a layer of sand that is then heated using the concentrated solar power to fire the sand into a glass material. His testing was carried out in the Egyptian desert in February 2011.

In the deserts of the world two elements dominate - sun and sand. The former offers a vast energy source of huge potential, the latter an almost unlimited supply of silica in the form of quartz. The experience of working in the desert with the Sun-Cutter led me directly to the idea of a new machine that could bring together these two elements. Silica sand when heated to melting point and allowed to cool solidifies as glass. This process of converting a powdery substance via a heating process into a solid form is known as sintering and has in recent years become a central process in design prototyping known as 3D printing or SLS (selective laser sintering). These 3D printers use laser technology to create very precise 3D objects from a variety of powdered plastics, resins and metals - the objects being the exact physical counterparts of the computer-drawn 3D designs inputted by the designer. By using the sun’s rays instead of a laser and sand instead of resins, I had the basis of an entirely new solar-powered machine and production process for making glass objects that taps into the abundant supplies of sun and sand to be found in the deserts of the world. Markus Kayser (2011)

The machine

The Solar-Sinter machine is based on the mechanical principles of a 3D printer. A large Fresnel lens (1.4 x 1.0 metre) is positioned so that it faces the sun at all times via an electronic sun-tracking device, which moves the lens in vertical and horizontal direction and rotates the entire machine about its base throughout the day. The lens is positioned with its focal point directed at the centre of the machine and at the height of the top of the sand box where the objects will be built up layer by layer. Stepper motors drive two aluminium frames that move the sand box in the X and Y axes. Within the box is a platform that can move the vat of sand along the vertical Z axis, lowering the box a set amount at the end of each layer cycle to allow fresh sand to be loaded and levelled at the focal point. Two photovoltaic panels provide electricity to charge a battery, which in turn drives the motors and electronics of the machine. The photovoltaic panels also act as a counterweight for the lens aided by additional weights made from bottles filled with sand.

The machine is run off an electronic board and can be controlled using a keypad and an LCD screen. Computer drawn models of the objects to be produced are inputted into the machine via an SD card. These files carry the code that directs the machine to move the sand box along the X, Y coordinates at a carefully calibrated speed, whilst the lens focuses a beam of light that produces temperatures between 1400°C and 1600°C, more than enough to melt the sand. Over a number of hours, layer by layer, an object is built within the confines of the sand box, only its uppermost layer visible at any one time. When the print is completed the object is allowed to cool before being dug out of the sand box. The objects have rough sandy reverse side whilst the top surface is hard glass. The exact colour of the resulting glass will depend on the composition of the sand, different deserts producing different results. By mixing sands, a combination of colours and material qualities may be achieved. Markus Kayser (2011)
6.0 Theory and Practice

6.1 Economies and Efficiencies

This technology is crucial for the continuation of Western Europe and America as competitive construction markets. China, India, Mexico and Brazil have a vastly larger labour force, this has been crucial to their 21st century boom in construction. In this technology we find a solution that can offer 1/5th current labour costs. Developed countries can take advantage of their position as academic and intellect based markets. We find we can no longer compete in manual labour, but we can still compete as 'brain-based' construction bases. Contour Craft (2004)

Automation of industries such as shoes, clothing and cars has resulted in a cost roughly 25% of manual labour. Using this we can suggest, that a move to automated construction methods will result in similar savings Contour Craft (2004)

The most expensive stage of any build is the construction stage, and it is directly dictated by time spend on site. The goal of this stage is to get a building to market, with every day spend on site a reduction in profitability. If we are to agree with Contour Crafting, that it is possible to print a house in 24 hours, compared to 3 -6 months, we can straight away envisage huge savings. For an economy to recover, we need buildings put to market well-built and fast.

The other obvious financial advantage is the major reduction in labour costs. While virtually every other sector of industry has experienced dramatic improvements in efficiency through automated manufacturing and technological innovation, the construction industry has not. The industry needs new materials combined with more efficient processes to reduce labour and fabrication costs. Contour Craft (2004)

Like many new technologies, contractors, architects, and engineers are slow and cautious of using new materials. However, with the ever increasing rise waste disposal, gradually the industry will move towards a more efficient, cost effect method of construction and 3DP could offer a solution.

Landfill Dumping Charges

2014 £80/tonne
2013 £72/tonne
2012 £64/tonne
2011 £56/tonne
2010 £48/tonne
2009 £40/tonne
2008 £32/tonne
2007 £24/tonne

Negative Efficiencies using Manual Labour

The construction industry, unlike most industries, is still heavily reliant on manual and skilled labour. 3DP could alleviate some of the current drawn back of this such as;

1. Labour efficiency is alarmingly low
2. Skilled workforce is vanishing
3. Work quality is low
4. Control of the construction site is insufficient and difficult
5. Accident rate at construction sites is high
6. Waste and trims are high (3 To 7 tons per average home; 40% of all materials used worldwide are for construction)
7. Low income housing and emergency shelters are critical and slow to build using conventional building methods
8. Construction is the largest sector of almost all economies. All other products are fabricated automatically – construction is still largely a manual task

Contour Craft (2004)

Construction & Non-Farm Labor Productivity Index (1964-2003)

Sources: US Dept. of Commerce, Bureau of Labor Statistics

- Construction Productivity Index (1964 = 100%)
- Non-Farm Productivity Index (1964 = 100%)

Index

6.0 Theory and Practice

6.1 Economies and Efficiencies (Cntd)

The age of the ‘Prefab’ has had the detrimental effect on 3DP. This was the industry’s first attempt at automation. Its main application was characterless apartment blocks and commercial units. It gained a reputation for its lack of flexibility and design potential. PreFab also brought with it large transportation and assembly costs. Originally PreFab’s big advantage was highly accurate building elements. However their creation required land hungry factories and meant a direct line to the building site was impossible. PreFab factories added to the embodied energy of all the raw materials needed. Even when a product used natural materials as part of its ingredients, excessive fossil fuels were needed to transport from origin, to factory, to site.

3DP avoids many of the pitfalls of PreFab. All materials needs are shipped directly and mixed on site. 3DP in some instances can also use ‘found on site’ materials, although this applies to a minority of sites. The logistics and cost to bring the equipment needed to set up a 3DP gantry, is less than that of a crane, needed to assemble precast units. The lead up time is also greatly reduced, as printing can begin once a design is finalised, contrasting that to PreFab construction were weeks if not months are need to manufacture the components.

Complex designs are created just as efficiently as straight line, a huge advance to PreFab or conventional methods. Where new moulds are required in PreFab, and excessive shuttering needed in conventional casts, 3DP needs no extra materials. As yet, no 3DP company has built a house, or habitable structure, hence, they (and this report) work on theory and possibilities - as this is a ‘in the minute’ state of technology. Companies like Contour Crafting have built sections such as full scale walls with insulation, reinforcement and openings for mechanical and electrical components, and they use these experiments to justify their claims of a ‘24 hour house with no waste at 1/5th the cost.’

Contour Craft (2004)
6.0 Theory and Practice

6.3 Material, Waste, and the Environment

Material

3DP offers the opportunity to for zero waste (of discarded unused materials). In Scotland, under the ZERO WASTE SCOTLAND incentive, we can look towards 3DP as a realistic waste reduction option. Conventional methods will never reach a point of zero waste. It is only through automation we can work towards such accuracies of materials that lead to zero waste. Raw materials are only used as needed in 3DP, allowing excess raw materials to be relocated. Raw materials such as cement are far easier to relocate than premixed concretes which have a short life span before solidifying. Computer Aided Design can accurately measure the needed raw materials allowing for zero waste.

In theory, 3DP is a low embodied construction method, as materials are brought directly to site, rather than going to a off-site factory first, before reaching the site. It also allows for, when applicable, raw materials found on site can be used, contrasting to a situation where raw materials found on site must leave site to be manufactured, and then return.

3DP also eliminates formwork. Using hybrid 3DP gantries, with a pour nozzle and a lifting arm, a complete building can be poured and cast without form work. However these house are very simple in design. Where a design calls for large cantilevers, temporary formwork would still be needed, however, for large volume and commercial projects, 3DP can, in theory, eliminate the disposal of unused material.

Scotland produces large quantities of waste – almost 20 million tonnes in 2008
This comes from a range of sources;

Household waste – 2.9Mt
Construction waste – 8.6Mt
Rest of the commercial and industrial sector – 7.9Mt
Construction waste = 44% of total Scottish waste
26% of construction waste is packaging
13% discarded unused raw materials

Devine (2011)
*SEPA Waste Data Digest 10
Zero Waste Scotland

3DP offers;
– less waste to landfill
– less site traffic
– lower carbon footprint

The reality of Change

Over the past 5 decades, there has been little change in the basic materials and methods used in construction
Highly manual basic methods of placement and assembly have been essentially constant. Improvements have occurred largely in construction equipment and in secondary components such as windows and doors.

The industry is highly fragmented and is dominated by small-to-mid-sized companies. This situation has stifled advances and innovation in new materials and production practices. There is little incentive for introduction or development of new materials or construction techniques. Companies use the same materials and techniques as the competition to survive due to the lack of an economically viable alternative, and building code compliance allows little room for experimentation or innovation.
According to Enrico Dini he has been testing a new material with exceptional results in strength. He has yet to release his figures but his claims that the material is as strong as re-enforced concrete seems questionable considering it does not use any re-enforcement.

The new material has been submitted to traction, compression and bending tests. The results have been extraordinary! The artificial sandstone created has excellent resistance properties. Effectively, the new process returns any type of sand, dust or gravel back to its original Compact Stone state. The Stone is very similar to Marble. The binder transforms any kind of sand into a marble-like material (i.e. a mineral with microcrystalline characteristics) and with a resistance and traction much superior to Portland Cement, so much so that there is no need to use iron to reinforce the structure. This artificial marble is indistinguishable from real marble and chemically it is one hundred percent environmentally friendly. 

Loughborough University have carried out more transparent testing relying on getting the mix right using standard concrete materials.

Cement and gypsum based materials have been used in the investigation. A key factor in the selection of these materials was having ubiquitous familiarity at an industrial level. Initial printing tests were carried out using various nozzle diameters from 4 to 22mm. Since the printing process requires a continuous high degree of control of the material during printing, a high-performance build material has been developed. The density of the concrete is approximately 2300kg/m3; the mix produces a high strength material, which is more than three times as strong in compression and in flexure as conventional cast construction materials. Less than 20% of the strength is lost with the printed material due to the presence of small voids created in layers of the printed material; however, the creation of a high strength mix, where the average compressive strength of the cast mix was in the range 100~110 MPa, has resulted in an acceptable strength for component manufacture, in excess of 80~88 MPa. 

6.0 Theory and Practice
6.4 Structural Integrity
7.0
Potential Applications

7.1
Disaster Relief

Architecture is increasingly being looked at to solve housing and humanitarian needs in disaster zones with organisations like the red cross and architecture for humanity actively investigating and pursuing new methods for quick and cost effective shelter. The two main limitations are time and money in any disaster zone. The current typical response is in 3 stages.

Stage 1: Emergency Shelter
Waterproof tarps and plastic sheeting. Lightweight and cheap to mass produce. More durable and adaptable than tents. Hot in warm weather, leaky in wet weather, difficult to keep clean and potentially hazardous spaces in which to cook. No insulation or sanitation. Average life span 1 year.

Stage 2: Transitional Shelter
Consists of a mix of emergency shelter supplies combined with more robust items, including salvaged building materials and kits containing cement, timber and steel framing, tin roofs and fixings. Provide ventilation, insulation and sanitation. Usually upgraded to provide permanent solution using local labour. Average life span of 2 years.

Stage 3: Permanent Housing
Requires large investment in construction, infrastructure and community services. Priority given to rebuilding roads, electricity and sewage system.

USAID(2011)

The above stages are typical of most disaster responses. Stage 1 difficulties are often compounded by access to site and lack of available materials. Transitional shelters tend to become the permanent option and are often prone to repeat disaster. Using a portable rapid additive manufacturing system the first two stages could conceivably be skipped with a permanent structure immediately erected. Printers could be loaded onto trucks or air lifted and reach affected zones as quickly as the first wave of aid. Clearing away debris would become the main hurdle. The main advantage of an in-situ 3d printer is its utilisation of local materials. Depending on the location the machine may be all that is required to be delivered with local materials providing the dominant construction material. This would dramatically reduce cost and labour while maintaining a local vernacular. If we take the Asian Tsunami as an example, over 280,000 people lost their lives but an estimates 1.1 million were left homeless. UN Secretary General Kofi Annan stated it would take 10 years to house all of those affected using current technology. With such large scale devastation could 3-D printing reduce cost and build time? The University of Southern California think so and have claimed they will demonstrate a compete printed house in 24hrs this year as an example of what is possible.
7.0 Potential Applications

7.2 Extraterrestrial Development

In January 2004, the American administration and NASA committed themselves to extending the time humans spend on the moon for lunar research. Contour Crafting is currently working with NASA to develop in-situ structures that take advantage of lunar resources and regolith as building material. The structures will, in theory, encompass radiation shielding, plumbing, electrical, and sensor networks.

The American Society Civil Engineers released a paper in 2006 on the legitimacy of lunar development. In their view, lunar regolith is a perfect aggregate and lends itself to concrete construction. They state, for lunar concrete construction, chemical admixtures are needed. Such chemical admixtures will help counter-act the problems of the air levels, water and gravity. The paper assumes that portland cement and water will be the binder of the aggregate materials used in making concrete.

Enrico Dini has also joined the lunar 3DP race in collaboration with European Space Agency and offers a more likely and logical direction with the application of Enrico Dini’s D-Shape printer. Dini’s D-Shape printer uses only sand and an inorganic bonding material, meaning the lack of water on the moon is not an obstruction. Again, in theory, Dini hopes to substitute sand with lunar dust.

Dini will carry out trials in a vacuum chamber at Alta Space’s facility in Pisa to ensure the process is possible in a low-atmosphere environment such as the moon.

This application, on a personal level, feels more applicable. Architects like their designs
8.0

Conclusion

3-D printing, in all of its forms, is a very exciting technology with huge potential but once probed it is clear that there are many potential problems and a lot of testing/development to be carried out before it can become a reality. It is always tempting to compare new technologies to previous ground breaking changes in architecture and construction. This is partly down to how slow the industry embraces change but equally, there are challenges that are not being met with our current building technologies. 3-D printing has allowed designers to start dreaming of ever more ambitious buildings attracting interest from a range of exciting collaborators. Since the later part of the last century, 3-d printing has developed quickly. Initially, rapid prototyping was the driving force. Today, the idea of a printer in every home is building momentum. The next obvious stage is large scale printers used in manufacturing and construction. Selective Laser Sintering has huge potential but is very unrefined in its current form (in large scale). Fused Deposition Modelling looks most likely to be the first system to be commercialised and used on-site within the next few years but requires a lot of the work to be done before printing (mixing etc.). The startling economic and energy benefits look great on paper but this is an area where further testing is essential to be taken seriously. It can be difficult to foresee new costs and problems in a new technology without real world application. The University of Southern California’s plans to use their printer to construct a house in 24 hrs this year maybe provide more questions than answers. Loughborough continue to develop their printer as a printer of parts that can be assembled on site but this seems more like a factory floor machine than something usable on site at present. Enrico Dini’s machine looks the most promising but the information released glosses over some of the more practical issues with using it e.g. time/ money/ finish etc. Markus Kayser’s machine has huge potential considering its two ingredients are sun and sand but again the finished product is unrefined and a considerable distance away from producing usable construction elements. The technology’s use in the immediate future may lay in disaster relief where it’s rapid implementation could create habitable structures within limited time, material and cost constraints thus potentially leading to it’s uptake in the construction industry. The European Space Agency’s involvement is exciting but before we start thinking about building on the moon, the technology must prove itself on Earth first.

We found, while researching for this report, the information to be very ambitious, rich in theory albeit lacking in practical data. This report is about taking a snapshot of an exciting technology in it’s present state. We feel it’s widespread use is at least a decade away if ever. We hope it will form an important part of the MArch knowledge based resource and help others understand the potential of this exciting new technology.

Emmett McNamara
Dan Shanahan.
Bibliography

Markus Kayser (2011) Solar Sinter Available at: [http://www.markuskayser.com/work/solarsinter/]
Contour Craft (2004) Description Available at: [http://craft.usc.edu/Description.html]

Websites

www.develop3d.com
www.bathsheba.com
www.hellasprototyping.com
www.rael-sanfratello.com
httpww.markuskayser.comworkssolarsinter
http://www.buildfreeform.com/index.php
http://www.bbc.co.uk/news/business-14282091
http://www.markuskayser.com/work/solarsinter/
http://www.contourcrafting.org/
http://ascelibrary.org/Proceedings/resource/2/ascecp/206/40339/66_1?isAuthorized=no
<table>
<thead>
<tr>
<th>Page</th>
<th>Image</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Various Sources - Referenced as single images below - compiled by author</td>
<td></td>
</tr>
</tbody>
</table>