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How can architecture meet the challenges of climate change?

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By

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Abstract

This dissertation is about 3D construction printing within architecture and its importance towards climate change, and how this could help architecture meet challenges to tackle climate change. The research that was taken place towards answering these questions is split up into three sections. The first chapter is where a brief history and information about 3D construction printers is talked about and later moves on towards the case study and exploration of the effects climate change has had on the Indian population and how their living conditions have also been affected. The final chapter explores the materials that could be used within 3D printing while also speaking about the damages caused by conventional concrete and how the cement industry is trying to tackle that problem. Some of the main findings from the research has been that the cement industry is making efforts towards tackling climate change but usually the pace at which they are working is very slow. This research has also shown that 3D construction printing is gaining more attraction and is becoming a larger industry day by day but it is still too early to make any large assumptions of whether this will be the future of construction or if it will stay in a niche market as it is in today's society.

Design Rationale

For the designed artefact I will create a 3D render of one of the homes that I would intend to build for the proposed affordable housing I address throughout the dissertation. I will be mainly working with the software Cinema 4D and Autodesk Fusion 360. On Fusion 360 is where I will be 3D modelling the house itself as I have found it more convenient to do so on there compared to Cinema 4D. On Cinema 4D I will be focusing more on creating the textures and materials that I will be adding to the home, and will also add furniture to show what it would look like if it were to be lived in. Cinema 4D will also be the software I will use to render out my 3D model into images that will be presented, I will also be inputting an HDRI image as the environment on C4D to create a

more realistic outcome of the house other than being a model shown within a blank environment surrounding it. The home I will be creating is very simple it will have enough room for a family, it will consist of 2 bedrooms, 1 bathroom, a kitchen, and a living/dining room. One of the bedrooms will be the master bedroom for a couple (parents), and the other room will be for the children, since the house won't be very big and will only have enough space to have a modest life, both bedrooms will be the same size. As the bedroom is usually only used for sleeping, this will allow the kitchen and living space to be larger which is important as these are the spaces families use the most and will have enough room for everyone in the family to move around freely and a good space to socialise and do family activities such as eating. The home will also be one-storey since the cost and execution of creating two-storey homes in the time being is a trickier process. The design of the house I created was fully done on Fusion 360, excluding the roof and all textures which were done on C4D but this means is I did not create any floor plan, the reason for not doing so is because this will not be the final design of the house. I also wanted to mainly show how the house would look in a 3D model as I was more interested in seeing how the texture of the 3D printing material would come out. The other materials used for this home were oak for the windows and doors, a metal grip roof sheet material and for the floor polished green concrete. The reason for creating a house for my designed artefact is because through my dissertation I will be proposing to create a community where such homes will be built with 3D printers to give a home to those who have either lost them due to natural disasters or those who require a better home to improve their living conditions.

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Introduction

The creation of architecture was to create physical environments in which people live, it is also more than that, as it is also part of our culture. It allows us to represent and create the identity of where we live and to showcase our surroundings through the design and use of local materials. The research looked at for this dissertation is about how the use of 3D printing and locally sourced materials within architecture could help tackle climate change and poor living conditions. Therefore the question for this paper is, How can architecture meet the challenges of climate change? This will be shown through research about the different materials that could be used within 3D printers for architectural sized structures, how these materials are made, and also how they are different to concrete and other materials used in our everyday construction methods. Even though articles such as the Business Insider article about Icons first house give out the impression that these 3D printed houses are fully 3D printed, they are not, the part that is 3D printed are the walls therefore for everything else you have to use other materials, that is why this paper also looks at the importance of why you should mainly use local materials found in your surrounding area, as this will stop having to import certain materials from other countries which contaminate the atmosphere as you would be having to use planes, cars, boats, and other forms of transportation that emit Carbon Dioxide (CO2) which is a greenhouse gas. Throughout the dissertation, I will be looking into two case studies one being a paper by the MIT Media Lab group Mediated Matter called DCP - Digital Constructions Environment which is about the first architectural-scale structure fabricated with the Digital Construction Platform(DCP), using the groups Print-In-Place construction technique. The second case study will be looking into the living conditions in India and looking into how 3D printed homes could benefit the majority of the population as many are living in very poor conditions. India is also one of the countries that are most affected by natural disasters therefore many people lose their homes every year due to these disasters and 3D printing could be a great alternative to the normal construction methods as it is cheaper, faster and also more sustainable.

This paper will include 3 chapters, the first chapter will be about why the main topic of the dissertation is 3D printing and the importance of this new technology, the 2nd chapter will be about how this technology could be implemented in a real-world scenario that is why I am looking into India as the place where this could one day take place in a large scale. Finally, the last chapter will be focusing mainly on how this would be a more sustainable method of construction, and how this could make architecture as a whole an advocate to battle climate change.

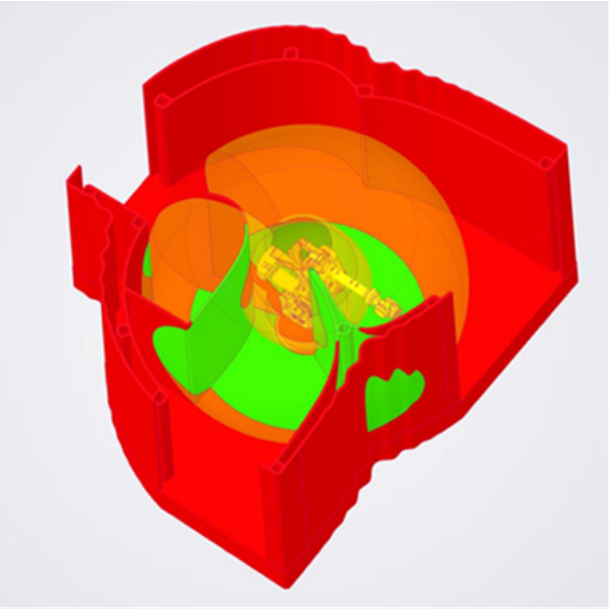
Chapter 1

History of 3D Printers

3D printing has been around for quite some time now, it was first introduced in the 1980s as additive fabrication. Which was a way to create 3D objects by 'adding layers of material starting from nothing, instead of removing useless material from a full block'(Savini and Savini, 2015). This idea was proposed by Charles W. Hull, which in 1986 Hull founded 3D Systems, this company is still selling 3D printers to this day where they range from entry-level kits to advanced commercial systems. Since Hull founded 3D Systems there are thousands of patents about 3D printing in the U.S. alone stemming from photopolymerization to fusion deposition to bio-printing (Savini and Savini, 2015). Due to the mass demand for 3D printed objects and 3D printers, they are now available to everyone and this has created a community of people who are innovating the results and products you can create using 3D printers, for instances housing. You now have several companies that are being founded that are focusing on using 3D printers to create architectural structures such as COBOD and Icon. There is also the group from MIT Media Lab called Mediated Matter who are researching and creating new ways to manufacture new materials using 3D printers and many other processes. This chapter will look into the new types of 3D printers that are used to create large scale structures such as homes.

Robotic Systems

Within 3D Construction Printing (3DCP) you have two different types of printers which are Robotic Systems and Gantry Systems. The robotic systems are known for being more mobile/ movable than the gantry systems since they run on a 6-axis movement. But the main drawback of the robotic systems is the limitation of the area that can be printed, therefore when using these systems you are not able to print full structures but only elements of a structure (Gantry vs robotic arms systems - 3D Construction Printers, n.d.). This is due to many factors one of them being the size of these machines if you are to look at an image of one of these printers such as the Cybe 3D printer. You can see that the robot itself is quite large meaning that you need quite a lot of clear space around it to be able to use it, this affects that printable area quite a lot. Most robotic arms are limited to a reach of about 330 degrees of rotation, meaning that there ends up being a dead zone where the arm cannot reach, therefore the robotic system can't print a full structure in one go instead you have to print it in elements and then bring those together at a later stage (Gantry vs robotic arms systems - 3D Construction Printers, n.d.). For an example of how limited the printing area is while using a printer such as the Cybe 3D printer which has a maximum 3-meter reach, this is an image taken from a paper written by COBOD showing the printable area of the CYBE compared to the BOD building. The green area is where the Cybe printer with a 3-meter reach can print on, and the red shows where the gantry system that COBOD used to create this building.



Printable area for a robot printer with a max 3 meter reach robot arm, typically supplied by robot printer suppliers. (Gantry vs robotic arms systems - 3D Construction Printers, n.d.)

Many have tried to solve this issue by either manually moving the robot itself to different points so

it prints from many different angles to be able to tackle large areas, or by adding rubber tracks which in turn would allow the robot to move freely. Allow this would technically work there is still the fact that this wouldn't change the fact that you cannot print the whole building in one print, therefore you would still need to print each element individually and assemble it on site. This means that you can print both on or off-site which is an advantage since printing off-site would mean a more controlled environment to print but this would mean that you would have to transport each element to the site which is not cheap. These are some of the problems that the robotic systems have which is why there are more companies today who are selling and working with gantry systems.

Gantry System

The Gantry system is the most used system within conventional 3D printers, 'a gantry system is a print head that moves back and forth along a supporting beam, which in turn moves in the other axis on a pair of support rails' (Potter, 2021). Most of the 3D printers that have moved from the experimental stage and are now in use for commercial production seem to use the gantry system these are companies like ICON which made the first 3D printed home for sale in the US, COBOD manufactures 3D concrete printers, and WinSun a Chinese concrete 3D printing company (Potter, 2021). A gantry system can be set up in many different ways, 'you can have an overhead gantry, with elevated rails that a boom then moves along, or you can have a pair of rails mounted to the ground, elevated rails require a larger support structure but ground-mounted rails require more extensive ground preparation to get a level rail surface' (Potter, 2021). Most construction 3D printers that have implemented the gantry systems are mostly split 50/50 between these setups. The reason why the gantry system is known and is used by most construction printers is due to their low cost, and are simple to execute, they are also known for being faster and more accurate than the robotic system. They are also much easier to work with on-site as you can hang a canvas over the support structure of the 3D printer itself this allows you to work in more environments than the robotic system meaning that you can print in more environments and areas than the robotic systems.

The main problem with this is that you have to build the printer in the areas where you are printing which can be a problem if you are printing in many different places in the same land, which can be time-consuming as you would have to take it down and commence to rebuilding it in another area of the site which could sometimes only be meters away if you wanted to make your building bigger in length and width. The main two printers that I have looked at are both the Icon printer Vulcan II and the Mediated Matter Digital Construction Platform which will be spoken about in the next section.

Vulcan II vs DCP (Gantry vs Robotic)

The main difference between these two Construction 3D printers is that the Vulcan II is a gantry system and the Digital Construction Platform is a Robotic system. The Vulcan II is a fairly new system only having been released in 2020, the main advantage of this system is that it is operated by a tablet and has been advertised to be very easy to run and to learn the software provided (Technology | ICON, 2021). This is groundbreaking within the construction 3D printers as many are quite difficult to use and need professional mechanics and workers who have been fully trained and are experienced with large scale 3D printers, this doesn't mean that the Vulcan II can be used by anyone but it allows more people to get started with running these machines due to the tablet app provided. It is also a gantry system that does not need to be assembled as it is brought to you by the people from Icon in their custom trailer and is ready to use after getting out of the trailer. The Vulcan II is used to specifically produce single-story buildings and is a cement-based printer. The Digital Construction Platform which is a new robotic system has not yet been released and is still in its experimental stage, but the main difference between this printer compared to most other robotic systems is both its size and mobility. It is much smaller than most robotic systems in the market at the moment, and the length of the arm is larger meaning it can print in areas that the conventional robotic system can't. Although this printer could be used to print conventional homes it is mainly targeted to create non-standard architectural structures which means this platform would

be better used to create structures that could mimic sculptures and other art forms within public spaces.

What System To Be Used

From looking into both the robotic and gantry systems to get an understanding of which one would be a better fit to create a mini-city/community of houses. We have concluded that the better option would be a gantry system as this would be the cheaper and faster option. This doesn't necessarily imply that the robotic system is worse than the gantry system but for a project that I am proposing for cheap living spaces the cost of execution would be too much to be able to make these homes affordable. For the time being, we are mainly looking into using the Vulcan II to create these homes as it seems to be the best for mobility, travel, setup, and use, as it is a simple and complex Construction 3D printer.

Chapter 2

Overview of Climate in India

Throughout the last few decades, India has been growing exponentially in both population and economic development, this has developed into India becoming the third-largest emitter of greenhouse gases in the world. The reason for India being one of the most susceptible countries to climate change and natural disasters is due to its geography and dependence on agriculture (Nelson). If India does not manage to change something to significantly reduce emission levels they could suffer a loss of 35 trillion USD, which would be a massive turning point in India's economic history. In 2021 India has suffered greatly from extreme weather conditions including Cyclones, a glacier collapse, heatwaves and floods. The flooding in general has caused a lot of damage to peoples homes specifically in Malad which is a northern suburb in India's financial hub Mumbai. There is an article on CNN which covers the topic of such weather conditions killing and destroying people's homes in this area, they talked to a man named Anish Yadav who has had his home

destroyed four times in the last three years due to flooding from monsoons which usually take place between June and September. This was not a severe problem before 2019 as there was a wall to protect the slums from flooding but it collapsed in July 2019 due to heavy rainfall (CNN). The area I will be focusing on is the Ambedkar Nagar Slum in Mumbai which is where the wall has collapsed and where people like Anish Yadav live. ‘The monsoon season is a natural weather phenomenon caused by warm, moist air moving across the Indian Ocean toward South Asia as the seasons change. But the climate crisis has caused the event to become more extreme and unpredictable’ (CNN). Mumbai is both known as the countries wealthiest city with several skyscrapers and luxury hotels and is also known as the countries second most populated city after Delhi with roughly 12 million people. Even though it is known as the wealthiest city in India around 65% of the population lives in poverty, where they live in shacks of tarp and tin in crowded slums (CNN).

Homes in Urban Slums

Most homes in Ambedkar Nagar are built by hammering down wooden poles, tying them together and then covering them with plastic sheets, and since this, all sits on soil whenever there is heavy rainfall and winds it is very easy for the house to fall apart as the soil is loosened by the rain (CNN). The image on the right is the home where Anish Yadav and his mother live at the moment and is a great example of how 65% of the population in Mumbai is living, which is no way to live in a city that is known for its wealth. Most of these houses are about 10 by 15 feet and the floor is made of dirt (CNN). Most families in this area keep their valuables in plastic bags in case they have to evacuate quickly but they cannot protect most things they own. So not only

Yadav family’s canvas hut in Ambedkar Nagar slum. Photo: CNN.

do they lose their home but they also end up losing most of their possessions and food if not all of it. The fact that these people don't have a permanent place to call home must be very difficult as they have to worry about being able to firstly provide a safe place to sleep for their family before being able to think about securing a job to sustain that home, and the people residing within them. After the last monsoon in September 2021, where most residents of Ambedkar Nagar lost their homes, were evacuated again to a school, where they remain to this day with little clean water or electricity and no toilets (CNN). They still don't know when they will be able to go back or get another home, the government had told them that they would be getting new homes within three to four days of being in the school, but nothing has been done (CNN). This has affected severely affected their well-being as most have lost their jobs meaning they have no money to provide food for their families let alone themselves (CNN).

About 35% of India's population live in urban slums, which is roughly 472 million people, these are the people who are being affected by the worsening climate crisis, and not much is being done to help them on the day to day basis. Losing their homes from the flooding is not the only long-term effect they have to endure, the secondary effects of flooding include the spread of waterborne diseases, groundwater contamination, and the loss of food supplies (CNN). This leads to affecting their health which in the long run could affect their jobs and source of income due to falling ill and not being able to reach certain targets and objectives that have to be met within their jobs.

Another way of calling towns such as these is either shanty towns or squatter settlements the meaning of these terms is that they are settlements of improvised buildings mainly known as either shanties or shacks, as mentioned before they are normally made of materials such as mud and wood. The main idea of a shantytown is that during its first stages of becoming a town it is effectively a squat as the area is not owned by homeowners legally, throughout its beginning, there is a lack of adequate infrastructures such as proper sanitation, safe water supply, electricity and

street drainage. Throughout time these places can develop their infrastructures and in some cases could even change into middle-class neighbourhoods. This can only happen with the right help and commitment of the community and governing power, as a lot of time and help is needed to do so. In this next section, I will be speaking about the redevelopments that had been put in place but over time had failed due to several circumstances, and will also speak on newer organisations who are trying to pick up what was left of such organisations and improve and finish what they couldn't.

Tackling the Problem

The big question here is how to improve the slums to be able to withstand these harsh weather conditions while keeping the budget as low as possible to allow these homes to be rented or bought at a low price. This problem has been attempted to be tackled before, but has been very slow over the years and has not worked due to 'lack of funding, insufficient participation, poor planning or the red tape of Indian bureaucracy' (CNN). A paper that talks about why these attempts have failed is a paper written by ESID (the Effective States and Inclusive Development) titled 'Lessons from India's Basic Services for the Urban Poor programme'. From the start of the paper, they talk about how the programme has failed to address urban poverty because of shortcomings in the design 'such as insufficient attention to tenure, lack of emphasis on the universalisation of basic services, low levels of participation by the urban poor, and unaffordability' (Mitlin and Thapa). One of the main problems from BSUP (the Basic Services for the Urban Poor) was the fact that they virtually got no input from civil society or community representatives from the areas in which they are trying to improve (Mitlin and Thapa). This is very important as they are the ones who will be living in these new spaces that they would have created for them, so it would have been very useful to hear from them and gather information on what necessities they might need that the BSUP might have not thought about.

There were many DUs (Dwelling Units) that did not meet the expectations of the communities such as a four-storey apartment block in Visakhapatnam. Where the design was prepared for communities that used biomass as fuel, there were no balconies, and the water supply had not been connected (Mitlin and Thapa), these are things that are very important in places such as India since the average temperature is around 25 degrees Celsius. Another example of this is in Patna, the standard designs of the apartment block did not account for those who owned livestock (which is very important for people as this might be a good income of food to feed their families), the construction was also of very poor quality, sewage and electricity connections also did not meet the standards of what it should be (Mitlin and Thapa). Furthermore, for both of these apartment blocks, they did not put any measurements of operations and maintenance for these apartments. The two projects in the cities of Visakhapatnam and Patna were in-site improvements meaning that the community living there did not have to relocate, while on the other hand in two other cities Bhopal and Pune they pretend a resettlement plan. They were asked to move further away from where they had grown up, and in many cases, the relocated location was smaller than the one before resulting in people being too cramped within their quarters, which is confusing as in many cases these redevelopments are done to allow these communities to have a bit more space in their homes than before. The image to the right is an example of one of the flats that residents of Bhopal got moved into, which the BSUP claimed was better than their older '*thickly clustered, low-quality huts with few community facilities*, on the other hand, the residents claim their prior living quarters were '*well-designed, good quality*

The block of flats residents of Bhopal got moved into. Photo: taken from 'Lessons from India's Basic Services for the Urban Poor programme

structures, for which they had 30-year leases. And have been forced to move to these apartments that are half the size, and are asked to pay 40% of costs' (Mitlin and Thapa).

On the contrary to the BSUP, there is another project in the works called Vision Mumbai, this group is looking to improve living conditions in Dharavi which is an area within Mumbai. This group is looking to replace the squatter settlements with higher quality flats, they are also going to bring more schools, shops, better health care centres, better roads and more jobs (White). The way this is going to be done is by the private developers buying this land which under the government's initiatives in 1995 they can do so at 25% of the fair market value and redevelop it (White). After buying this land and obtaining 70% of its citizen's consent, the project is moving forward by removing occupants and re-housing them in a free of cost multi-story building, however, this can only be offered to occupants who have been in the residence before January 1st of 2000 (White).

Examples of 3D printed Communities

An example of a community that has been built solely using 3D construction printers is a project which was done by New Story a San Francisco nonprofit organization that provides housing to communities under extreme poverty, in partnership with Échale a social housing production company in Mexico and Icon which is the company that created the Vulcan II printer (Kamin). This project started in 2019 and was called the first community of 3D printed homes, after two years of the pandemic it is said that there are either 200 homes built or under construction, 10 of which were printed on-site using the Vulcan II printer (Kamin). They are also planning to build roads, a football field, a school, a market and a library shortly, meaning that not only will this community bring better living conditions but will also bring in jobs that will help everyone around the community, and also bringing education. This has helped many residents in the Mexican state of Tabasco for example Pedro García Hernández who is a carpenter in Tabasco had lived in a home with dirt floors and during the rainy season was very prone to flooding. Also because he is a carpenter he had his workspace in the home all the dust from his projects ended up getting all around the home covering

everything within the home (Kamin). These homes that were built in Mexico are a great way of testing if these structures work in the long wrong, it is said that they can tolerate many natural disasters, and this was proven when the homes withstood a magnitude 7.4 earthquake (Kamin).

After the News broke out about this community of 3D printed homes in Mexico some other companies started doing the same thing such as Palari Homes and the construction company Mighty Buildings who partnered up. Announced a $15 million planned community of more than a dozen homes in the area of Rancho Mirage, California, after this was announced they had gotten a great response from the community and have received more than 1,000 submissions on the waiting list (Kamin). Icon has also started two other projects, the first was with 3Strands and Den Property Group who teamed up to create four homes in Austin to be sold on the market. They also printed homes in the Community First Village in Austin which is a village of 51-acres planned to offer affordable, permanent housing and a supportive community for men and women who are coming out of homelessness (Kamin). Although a lot more companies and people are starting to learn and talk more about 3D printed homes, and just last year the market grew 21 percent, and a manufacturing company named Hubs is predicting that it will double in size over the next five years it is still not a concrete statement (Kamin). As mentioned by Henry D'Esposito a construction researcher at JLL, a commercial real estate firm "*It really is a very effective and efficient way to build a small segment of properties, but it's not something that applies across the broader commercial real estate ecosystem. We don't know exactly how these buildings will perform over decades or what the long-term value retention will be for them" (Kamin).*

Chapter 3

Introduction

Within the field of Architecture, the construction industry is a key factor in seeing the architects vision come to life, even though this industry has such importance and attention they have

not been able to innovate the execution of a task for a very long time. They tend to use the same traditional process that has been used for many years, and this tends to create a lot of waste and have a large effect on our climate which is now being heavily damaged every day (Sriram Renganathan). This chapter will inform the reader of the difference in how much less damage this industry will cause our planet by adopting new processes such as 3D Printers also known as Additive Manufacturing. Some of the pros of adopting such a process would be better creativity, design flexibility, less material waste, lower carbon footprint, and more robust structures (Sriram Renganathan). Chapter 1 talked about the history of 3D printers and the difference between the two main large construction printers the robotic system and gantry system, in this chapter we will be focusing more on the materials that are used to create such structures with the printers.

Concrete

Concrete is the worlds most used material, it is what makes bridges, roads, dams, and construction, and not surprisingly it is the highest consumed product on earth besides water (Ramsden). The problem with concrete being the second-highest consumed product is the fact that it releases an extreme amount of CO2 into the atmosphere yearly, if the consumption and manufacturing of concrete doesn't slow down or change, the environment will continue to be polluted with over 4 billion tonnes of carbon dioxide annually due to the construction industry (Ramsden). The way concrete is constructed is by using cement which is mixed with an aggregate, which in this case would be a grainy blend of materials such as stone and sand, after this mixture is finished you pour the concrete into a mould which is then left till harden (Ramsden). 'The aggregates are sourced from a local body of water and crushed in a natural procedure'(Ramsden) this process is mainly not damaging to the atmosphere as it releases little to no carbon emissions, on the other hand, cement itself is the greater problem as it leaves large amounts of carbon footprints. According to Roger Warburton in an article written for ecoRI News, 'concrete currently accounts

for about 8 percent of the carbon dioxide being emitted into the atmosphere, dwarfing the aviation industry's contribution of 2.5 per cent (Warburton).

The main contribution towards this 8 percent is the process of creating cement, the process is done by firing limestone, clay, and other materials in a kiln. What creates the CO2 to be emitted from this process is the energy used to burn the materials, and it is also the chemical reaction that is produced when the mixture is exposed to heat. 'According to the National Ready Mixed Concrete Association, each pound of concrete releases 0.93 pounds of carbon dioxide' (Ramsden). The damage it causes to the environment goes beyond the CO2 emissions and climate change. 'Impacts can include acid rain as a result of emissions of sulphur dioxide, nitrogen dioxide and nitric oxide; health risks of locally high concentrations of cement kiln dust, and the depletion of drinking water supplies' (Van den Heede and De Belie). Even though it is known how much damage concrete has caused our planet and is still causing, it is still the main material used for construction due to its affordability, and the fact that it can be produced almost anywhere and has all the right structural qualities that you want to build with for a durable building or infrastructure (Rodgers).

Several companies around the world have designed solutions to help improve the concrete industry to become environmentally friendly, and many have decided to take immediate action. Some of these companies are Lafargholcim, Anhui Conch, China National Building Materials, HeidelberCement, Cemex, and Portland Cement. The largest company of them all is Lafargeholcim, in recent years they have been working to erase their environmental footprint. Since 1990 they have managed to lower their carbon emissions by 25%, and are hoping to soon reach net-zero emissions (Ramsden). The CEO has stated in the past '*I will not stop pushing the boundaries on our net-zero journey with rigorous science-based targets. At LafargeHolcim we are accelerating circular and low-carbon solutions to lead the way in green construction* (Ramsden). Following the efforts made by LahargeHolcim other companies such as China National Building materials and Cemex have followed their footsteps in improving their footprints. The name for this new type of concrete is

called green concrete which means ‘Green concrete is defined as a concrete which uses waste material as at least one of its components, or its production process does not lead to environmental destruction, or it has high performance and life cycle sustainability’ (Suhendro).

Some of the many waste materials used to create green concrete are slag, power plant wastes, recycled concrete, mining and quarrying wastes, waste glass, incinerator residue, red mud, burnt clay, sawdust, combustion ash and foundry sand (TheConstructor). As well as using waste materials there are a few alternative environmental requirements with which the green concrete structure has to comply with and these are CO2 emissions shall be reduced by at least 30%, at least 20% of the concrete shall be residual products used as aggregate, use of concrete industries own residual products, use of new types of residual products previously landfilled or disposed of in other ways, CO2-neutral waste-derived fuels shall substitute fossil fuels in the cement production by at least 10% (TheConstructor). Other environmental goals and intentions that are in place with green concrete are that they do not use any materials which contain substances on the Environmental Protection Agency’s list of unwanted materials, this is to not reduce the ability to recycle green concrete compared to conventional concrete (TheConstructor). If we were to look at the advantages and limitations of green concrete you would see that the advantages are the “*increased use of waste products within the concrete industry by 20%, no environmental pollution and sustainable development. Requires less maintenance and repairs, better workability than conventional concrete, good thermal resistance and fire-resistant, compressive strength behaviour of ceracrete with the water-cement ratio is similar to conventional concrete, the flexural strength of green concur is almost equal to that of conventional concrete*” (TheConstructor). On the other hand, there are fewer limitations of green concrete but are still of importance “*By using stainless steel, cost of reinforcement increases. Structures constructed with green concrete have comparatively less life than structures with conventional concrete. Split tension of green concrete is less than that of conventional concrete” (TheConstructor).*

Additive Fabrication Materials

Although many of these companies are starting to work in improving the way concrete is produced and the materials that are used to create it, there is a new industry that is getting bigger by the day and that is the 3D Construction printer industry. The 3D printing concrete which is the main material used when building structures such as homes is said to be extremely environmentally friendly as it reduces waste and CO2 emissions. For example, a materials technology company called Fortera has been working in producing innovative cement that reduces CO2 emission by 60% compared to traditional cement (Castenson). This company has also recently teamed up with a California based 3D printing construction company Mighty Buildings. This partnership was created to help advance Mighty Building's mission which is to address the housing availability crisis while becoming carbon neutral by 2028, and this will hopefully help in leading the way forward for the construction industry (Castenson). The way that Fortera have reduced their emission by 60% is explained by their vice president Has Farsad, '*There isn't a lot you can do to reduce the CO2 in cement. Traditional cement production takes limestone, grinds it and burn it. During that process, 44% of the weight of the limestone burns off as a gas. We want to make it as efficient as possible, but fundamentally when you burn limestone, you release CO2. It is unavoidable. To make our cement, we roll the CO2 back into the finished product, keeping the CO2 intact. Whatever you build now has incorporated, instead of having it released'* (Castenson).

The Mighty Building company is not the only one innovating and working with new sustainable materials, an Italian start-up under the name of WASP has been working in creating 3D printed sustainable shelters at minimum costs using naturally available local materials (Sriram Renganathan). In the case of WASP, they did not create a new form of cement but created a new 3D printable material mix, which is earth-based consisting of 25% soil (30% clay/ 40% silt/ 30% sand), 40% straw chopped rice, 25% rice husk and 10% hydraulic lime (Sriram Renganathan). This mix, in general, is very interesting as they use materials that are available to them in their surroundings,

meaning you also lower the carbon emissions by not having to transport materials from other countries, as you are using materials that were formed in the space where you are building. This is exactly how the homes in India will be created for this project, I will be looking into the materials and resources that are available to use in the surrounding areas of Mumbai and the surrounding regions.

The creation of these new additive fabrication materials will not only be used to create structures on the planet of earth, this new technology will reach other planets such as Mars. A company called Ai SpaceFactory has been working on a project named Marsha prototype which was a winning proposal in the 'NASA Centennial Challenge' contest (Souza). The idea of this project is to create 3D constructed structures in Mars, where people could technically live in to be able to colonise Mars, this would be the first colony of humans outside of Earth. The concept for this project is to use local materials on Mars to create a material that could be printed. The current proposal for such a material is to use a mixture of basalt fibre which is extracted from Martian rocks and renewable bioplastic (polylactic acid or PLA) that would be processed from plants that could be grown on Mars (Souza). This recyclable plastic was tested in NASA's strength, durability and crushing tests and the results were that it is stronger than concrete, this shows how this new technology is something to look forward to in the future as it will be the new norm within construction and architecture.

The Moon is also another great example of where this new technology could be used, there is research to create such structures in the moon using a material called lunar concrete. Lunar concrete would be created using a mixture of powdery soil found all over the surface of the Moon which is known as lunar regolith (Souza). The interesting thing about how this material would be made is that to bind and create this concrete astronauts could use their urine as the binding ingredient. "*The researchers found that adding urea to the lunar geopolymer mix, a construction material similar to concrete, worked better than other common plasticisers like naphthalene or*

polycarboxylate to reduce the need for water. The mixture coming out of a 3D printer proved to be stronger and maintained good workability" (Souza). The outcomes of such research could not only improve our chances of creating shelters and homes on other planets but could also help in providing more sustainable methods of creating materials that are needed on Earth. For example, if the use of urine as a bonding tool is proved this could effectively reduce the use of water in such methods which means the consumption of water would dramatically lower, and would help reduce the damage to the environment since there isn't an abundant amount of drinking water and to make water drinkable it goes through a process which uses fossil fuels to be able to power the filtration systems.

3D printing of buildings has been identified as a method that in the future when widely used by many construction companies could potentially improve projects, create organic shapes, reduce material consumption, construction time, necessary labour, logistical demands, and future costs (Souza). Researchers from the University of Texas have also said as pointed out throughout this chapter that "*considerable attention has been paid to the search for more environmentally sustainable alternatives to concrete, especially soil itself, which can be harvested and planted without the need to transport materials over long distances, allowing for a considerably reduced carbon footprint and built-in energy costs"* (Souza).

Materials in India

India has a wide range of minerals and natural resources, although they do lack some critical resources such as cultivable land, water, timber, and known petroleum reserves are low (Schwartzberg and Wolpert). Even though they lack these resources, they are very rich in minerals and many of those will be very useful to use in creating both 3D printing material mix, and will also help with creating the rest of the homes such as roofing, windows, doors and all the rest. The many

minerals that are available in India are Iron ore and ferroalloys which are amongst the most abundant in the area. Other metallic minerals include copper, bauxite (the principal ore of aluminium), zinc, lead, gold, and silver. Also amongst important nonmetallic and non-fuel minerals are limestone, dolomite, rock phosphate, building stones, ceramic clays, mica, gypsum, fluorspar, magnesite, graphite, and diamonds (Schwartzberg and Wolpert). The fact that India has such a vast variety of resources is a great example of why it is a perfect location to do such a project. As you can use local materials it will help with keeping this project environmentally friendly because you aren't contaminating other countries to create a project someplace else. This is something that happens all the time around the world, most countries that have amazing architecture and infrastructures in place have almost always gotten their resources from other countries and in turn leaving them completely contaminated. Which has a large effect on those poorer countries as they are left to deal with such problems that are affecting both their wildlife and their population's health.

Conclusion

Overall this paper has looked at the history and different types of 3D construction printers available in today's market also looked into India specifically the surrounding areas of Mumbai and how it has been affected by climate change and how the impoverished population's living conditions have been affected due to it. Finally looked into the effects that the concrete industry has had on our climate and how this could be changed with the introduction of 3D printed concrete and other materials used within the 3D printing industry in a larger space. The question that was asked at the start of this paper was, How can Architecture meet the challenges of climate change? The main idea that I had proposed from the beginning of the paper was that the use of 3D printing and the use of materials such as concrete filaments for the printers, would both cut down the use of

standard concrete and create suitable homes for those impoverished at a lower cost and would be finished at a faster rate than today's standard construction time for such homes. The cutting down of standard concrete would also mean that the cement industry would not be producing as much cement as it does today in turn it would lower the percentage of how much damage this industry has been causing the environment for as long as we can remember.

Through the research that has taken place for this paper, I have found that the concrete industry has been making efforts towards creating a cleaner process of producing cement called green concrete. Although they have been putting a lot of time and money towards making this new material the norm within architecture it still has a long way to go, and will most likely not be used worldwide anytime soon. I believe this is due to it not being a completely new material, and when having the option to use the standard cement which is the longer-lasting out of the two most would stick with such material. On the other hand, materials that have been created to be used with the 3D printers are technically completely new materials which help gain more traction as most companies providing them such as WASP who have created their own using only locally sourced materials, don't have to go through a lot of the political sides of a big corporation that has been running for many years. 3D construction printing is still in its early stages which means you can't necessarily say whether it's going to be the next big thing within architecture and construction, it would be in the best interest of the planet if it were to become a household industry within the construction of homes due to its upsides of challenging and meeting the requirements of tackling climate change. It would also help create better living conditions for those who are affected by the backlash of climate change and such weather catastrophes, this is because you can build these homes fairly quickly and at a very low cost which is very important as most governments aren't interested in spending too much money on public housing. That is the main reason why there are so many problems with public housing due to the lack of attention and maintenance put towards them.

To conclude, this paper has given an insight into a way architecture could meet the challenges of climate change. To truly state that this is the best way to challenge such things is not something you could state as it is still early stages for this industry and we are yet to see this being shown in a large context such as redeveloping squatter settlements with homes such as the one I have proposed.

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