3D Printing a Possible Solution to Brazil's Housing

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

Latin America struggles with housing solutions. "One in three families in Latin America and the Caribbean, or 59 million people, live in dwellings that are either unsuitable for habitation or are built with poor materials and lack basic infrastructure services. As many as 2 million out of the 3 million households that spring up annually in Latin American cities are forced to settle in informal housing, such as slums, because of insufficient supply of adequate and affordable dwellings" (Inter-American Development Bank News Release, 2012, para. 2). As the largest country in Latin America, Brazil has been struggling with housing for the low classes, especially in the urban areas. With a significant amount of the population living in urban areas, most of Brazil's big cities see themselves facing over-population.

People and companies work every day to find less expensive and faster ways to build the infrastructures we need to improve our standard of living. With limited support from government agencies for affordable housing, activists and entrepreneurs are turning to new technological interventions. Most of the inventions are still in an experimental stage, but there is potential for 3D construction in dense urban settings. This type of construction minimizes costs and construction time by using 3D printing as the main tool to build the desired infrastructure. There are still unanswered questions regarding this new construction method since there are not many large-scale projects at the time, but it might be a useful tool to face the housing issues.

This paper presents the different problems Brazil is facing in housing and construction before turning to the possibility of 3D printing construction serving as a tool to improve these challenges. Current applications of 3D printing, particularly in the process of adopting advanced technologies for development projects, will be used to compare different approaches and determine which approach might be more appropriate.

Literature Review: Avoiding the Technological Fix in Development

Throughout the years, there have been many situations where people have relied on technology to fix social problems in different countries around the world. When implementing new technologies in countries that don't have the infrastructure or the specialized knowledge, you have to adapt the technology to the specific characteristics of the area you are working on. This adaptation is not an easy process because the social, cultural, and ethical aspects of the communities the technology is intended for must be considered. In his study Thomas (2008) states that "according to Robinson (1983) the definition of an "appropriate technology" should incorporate the analysis of different variables: availability of qualified workforce and its relative value, capital invested in the machinery, in the supplies, and in the production process, and the availability of management human resources. These variables should reflect the scarcity or abundance of particular resources in the composition of the necessary supplies, substituting capital (for example, in an economy where manpower is abundant and capital is scarce)." Studying examples of people applying appropriate technology to communities in need will help us understand the factors that come into play when considering 3D printing in Brazil.

In Success and Failure in Technology Transfer: The Story of the Handpump, Hughes explains how the introduction of hand pumps was a technology that was believed to fix one of the biggest issues encountered by the African communities, but factors that didn't come into consideration have made this technology lack its impact. Africa faces huge problems to provides its citizens with clean water, especially in the rural areas. The people who brought this innovation didn't consider the cultural barriers that they should overpass to ensure its success.

In the short-term, there was hope that the impact was going to keep growing. But, in the long-term researchers noted three mayor factors pushing against people using the hand pumps.

The first factor was that these communities were not fully educated and didn't take into consideration the lack of importance that members would give clean water. Second, the hand pumps were providing water to large amounts of people and needed replacement after short periods of time. The small villages in Africa had no replacements parts which made them return to their usual ways of accessing water. And the last influencing factor to this technology's failure, was that these people were so used to the flavor of the water provided by their previous methods, that they would rather drink from the dirty water.

The hand pump represents an example of a technology that had the potential to fix a problem in for a significant population but lack of education and interaction with the community members made the whole system fail. Had some of these factors been addressed beforehand the impact of the project could have been much greater. Hughes (page 133) concludes: "The transfer of technology will almost always require adaptation to the artifacts they centred on and the environment into which they were introduced. It will be necessary to understand the physical, social and cultural aspects of the new environment. However, to identify what adaptations are needed it is necessary to examine the assumptions the donors have about the technology in question and why people should want to adopt it. Understanding the culture of the donors will be as important as understanding the culture of the recipients".

An example of effective appropriate tech is the implementation of solar-powered canoes in the Amazon River (Kafyeke, 2017). Aliados, Kara Solar Foundation and The Achuar Nation of Ecuador (NAE) are working together towards building an environmentally friendly solution to the transportation barriers being faced by the indigenous communities in Ecuador and Peru around the Amazon River. Their idea is based on using solar power to provide energy to their existent transportation methods and then fix other social problems along the way. Kafyeke

(2017) notes, “Kara Solar’s vision is not limited to the boat but rather includes a whole transportation system where the Achuar can be driven to school or the doctor with the solar boat. It should also be able to facilitate the delivery of food and generate employment” (Kafyeke, 2017, para. 6).

Instead of using this technology as a business venture, these foundations are using the invention to create more stability and connectivity for the communities in the Amazon and Andes. “We firmly believe that conservation of the Amazon and Andes ecosystems is vital for the well-being of our planet. Yet, we’ve also seen that conservation that neglects local people’s livelihoods is not effective in the long-term.” (“Our Approach”, Los Aliados) A more efficient and developed transportation system provides these communities with better access to products, distributors, and other markets. To relate the project with the people living in this areas, Kara Solar and Aliados Foundations are developing other aspects of these indigenous societies based on the created transportation platform. Their three main approaches were: Farm and Forest, Community Enterprise and Market Development. “Our three-pronged model a) builds farm management and forest conservation capacity, b) builds local organizational and leadership capacity, and c) links community enterprise to sustainable markets through innovative business models.” (“Our Approach”, Los Aliados, para. 3)

In Farm and Forest, Los Aliados Organization plan on starting by creating an agroforestry model to increase the amount of farming production and to cultivate non-traditional products. Additionally, they are developing a network of markets that would be more accessible using the solar powered canoes. These two plans together will give the farmers in these communities a more stable and diverse trading market for their products. For the community enterprise aspect, the new products will help regulating fluctuations on the products. These

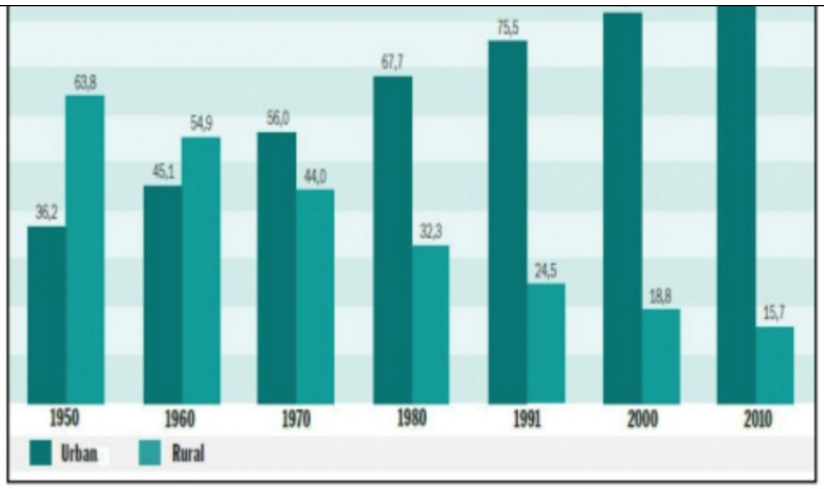
foundations also plan in using respected members of the communities to give training and leadership mentorship to the different community members. And last but not least, the market development area would be heavily influenced by also strengthening the connections between distributors and the communities. The solar-powered canoes developed in partnership with Kara Solar would ease the process of moving the product from the Amazon and the Andes to stores in cities in Peru and Ecuador.

Kara Solar's project in the Amazon successfully used solar panels as a technology to work on social problems being faced by a community. Instead of trying to change their transportation methods, these foundations brought the solar panel technology as upgrade to create the solar powered canoe. Then, developed different aspects of the community based upon the improvements the new transportation system provided.

Rapid Urbanization and Brazil's Housing Situation

The trend towards urbanization has caused an uncontrollable demand on Brazil's big cities. Figure 1 compares the ratio of citizens living in rural areas versus the citizens living in urban areas. From 1950 to 2010, there has been a massive increase in what Brazilians see as their optimal living environment shown by the 50% increase in the population living in the urban areas. The major housing changes faced by the country happened in such a short time, that cities didn't have the infrastructure ready to sustain those amounts of populations. This phenomenon, that first started in Rio, pushed people to live in places with no infrastructure or legal permits, known as Favelas. Most of the housing units don't have proper sewage, access to clean water, or waste collection system.

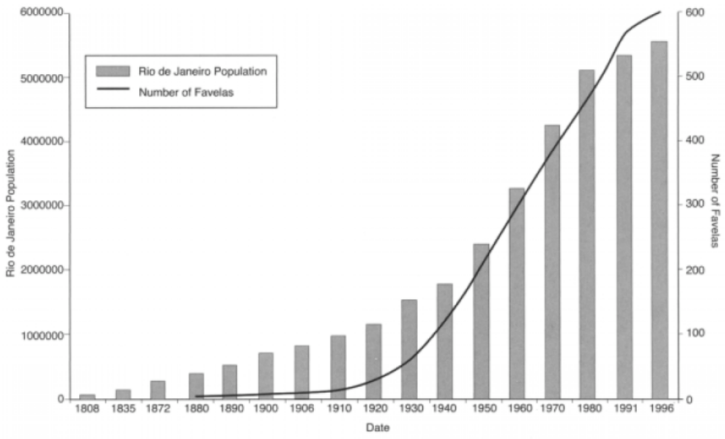
Figure 1
Population evolution by place of residence - Brazil, 1950 - 2010 (in %)



Source: DIEESE (2011, p.63), based on IBGE Censuses data

The famous favelas are an indicator of the overpopulation and the lack of housing units in the sectors of Brazil with the most business opportunities. Most of the low-income workers who come to the city looking for more opportunities resort to Favelas to look for a home. This is due to the fact that housing industry, specifically for the low-income households, cannot supply the demand being faced for living spaces in urban areas. The growth of favelas represents the failure to establish decent and affordable households to counter the massive trend towards urban living.

Figure 2
The growth of Rio's favelas in relation to the city's population increase



Source: O'Hare, G. and Barke, M. (2002, page 233)

Figure 2 shows the relationship between the rise of urbanization and the growth of favelas in the country. It has become concerning the percentage of the population who rely on these living conditions, and now parties inside the country are prioritizing projects relating to this issue.

Projects in Brazil

There is an obvious market for more affordable construction technologies in Brazil, but the construction industry's inefficiency is also a reason to consider other options. Although Brazil has one of the world's biggest economies, their infrastructure is underdeveloped. The government has tried to alleviate these problems with various projects but there has been a slower progress than expected. Figure 3 displays the percentage of projects that take longer than the expected time in Brazil.

Figure 3
Percentage of Projects Delayed in Brazil

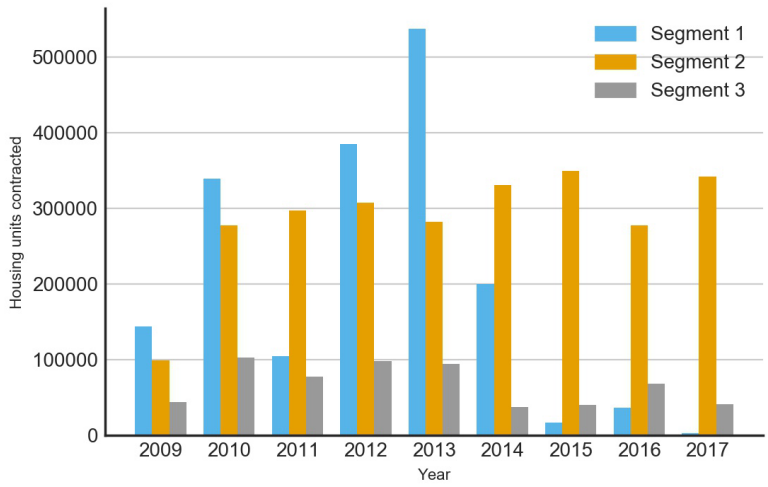
Planned time (month)	Number of projects	Sample percentage	Number of delayed projects	Percentage of delayed sample per planned time
18	2	1.40%	1	50.00%
24	7	4.90%	6	85.71%
32	16	11.19%	14	87.50%
34	1	0.70%	1	100.00%
36	61	42.66%	55	90.16%
37	1	0.70%	1	100.00%
40	3	2.10%	1	33.33%
42	22	15.38%	18	81.82%
48	26	18.18%	18	69.23%
62	3	2.10%	1	33.33%

Source: Furtado Maués et al (2017, page 171)

Even the 9th biggest economy in the world has problems when dealing with 81.7% delay on the projects being done. This also impacts on the budget on other projects happening because the extended costs in these delayed developments puts the government in a situation where it seems limited, and most importantly repeats the cycle to worsen the existing issues.

Today, Minha Casa Minha Vida is the biggest housing project being worked on by the state of Brazil. The program launched in 2009 and its purpose is to provide housing to millions of families who are currently in not optimal living conditions, mainly in the favelas, to reduce cities over population. The project has been providing residences to many families along the country but has also encountered several difficulties with the budget causing project delays. The idea behind the Minha Casa Minha Vida project was developing numerous buildings to serve as single and multi-family housing. These buildings would be placed in the outskirts of the major cities in Brazil to battle over-population in the cities. The Minha Casa Minha Vida project has had funding issues through the different stages of the project. 3D printing could be a possible solution to reducing the cost of certain aspects in the construction of the project but would also require some changes in the plans. Some of the potential cost reductions would be in material waste reduction, construction time, and labor costs.

Figure 4
Housing units contracted in MCMV



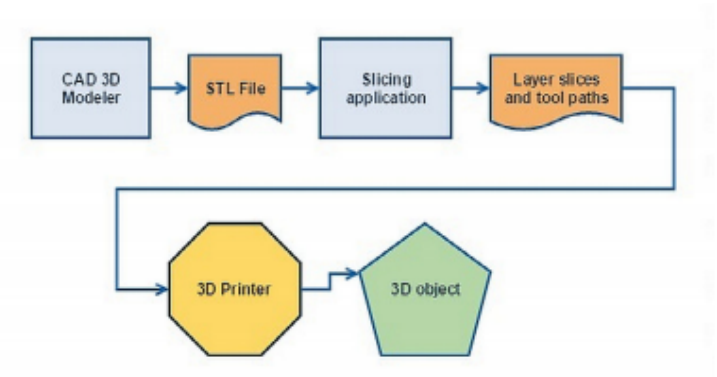
Source: Squarize Chagas, A. L., Malvezzi Rocha, G. (2019, page 7)

The Minha Casa Minha Vida program works with three separate groups of applicants divided by the family's monthly income. Segment 1 includes all families who earn less than three minimum wages, Segment 2 covers families that earn between three to six minimum wages and Segment 3 is people from six to ten minimum wages. Segment 1 is the segment with the biggest challenge since their incomes can barely cover the rising prices of Brazil housing units. Figure 4 shows the contracted units based on segment, after 2013 people from Segment 1 started seeing a significant change in the number of contracted units to people within their monthly salary. This represents a new obstacle that the project is facing. The segment with the most need is the one that has been the less benefited in the later years of the program. Vanessa Barbara (*The New York Times*, 2014, para. 2) states in one of her articles that "someone making the minimum wage in Brazil ($325 a month) can afford to rent only a three-room shack in the crime-ridden Favela Paraisópolis ($280), leaving him practically nothing left over to live on". Barbara comments on how limited the housing opportunities are in the open housing market for those in Segment 1. Additionally with the struggles of the Minha Casa Minha Vida project, people between zero to three minimum wages find themselves in a vulnerable position leaving the doors open for new technologies like 3D printing construction to innovate and help reach these areas in need.

3D Printing Construction

Due to the established problems being faced by the housing and construction industry, companies have actively been looking for different solutions. In Brazil, a start-up has already begun research and development to create their own 3D printing technology.

Figure 5
Typical workflow of 3D printing process



Source: Hager, I., Goloka, A., Putanowicz, R. (2016)

Figure 5 shows what the common process for 3D printing construction. As seen in the diagram, this type of construction has no intermediaries between the virtual files and the development itself which helps reduce construction time. There are many methods and materials being used for 3D printed construction. New Story Charity, an organization that works on fighting homelessness around the world, and ICON, a construction company who developed their own 3D printer, are partnering on 3D printed low-income housing in their project. Anas Essop (2019) comments: "In 2018, New Story and its partner ICON were able to 3D print a house in Austin, Texas in 48 hours as a proof of concept, at a cost of less than $4000 using an early iteration of the Vulcan 3D printer from ICON. Now, collaborating with Fuseproject, New Story will utilize the updated Vulcan 2 construction 3D printer to produce homes at an undisclosed location in Latin America, reportedly in as little as 24 hours and costing $6,000 for each building".

Although material prices and wages vary by country and the price estimates can fluctuate, when using the Vulcan 2 house costs are within affordable range for those who need them. According to Kenneth Rapoza (Forbes, 2013) "Average price per square meter in São Paulo was R$6,806, or around $3,403. Rio was even worse and has become the most expensive city in

Brazil when consider square meter pricing. In Rio, it's over R$8,300, or around $4,000". If we compare the average price per square meter to the total cost of construction an ICON 3D printed house, it would be the equivalent a 2 sq. mt. house.

One of the challenges faced, when using this type of construction, is there exists a size restriction for the infrastructure being developed. Most of the projects that used this tool are focused on the constructing single family houses. This aspect of 3D printing construction limits certain possible uses because there is still not a viable way of 3D printing large multi-family housing. The Vulcan 2 can print walls up to 8.5 feet (2.6 meters) high and infinite length, and foundation 28 feet (8.5 meters) wide. The Vulcan 2 does limit the construction options to single story buildings, but it prints 5 to 7 inches per second which would permit a really fast printing pace. ICON also says that their new 3D printer just need between 4 to 6 operators which would reduce the number of workers needed per unit on most constructions. The material used for the Vulcan 2 is call Lavacrete. Lavacrete is also based on Portland Cement but it is more pumplable to facilitate construction. It is similar to concrete and would serve the purpose in Brazil. When considering its viability on the Minha Casa Minha Vida projects, the projects has standardized dimensions for single family and multifamily houses. When taking into consideration the existing dimensions/requirements they have determined for the project, the Vulcan 2 meets all of them regarding construction/structure. Since they had already accounted for these dimensions, the existing sites should work perfectly and space should be sufficient to meet the standards. The only difference, between the 3D printed design versus the traditionally built design, would be the materials used because the Vuclan 2 needs to use Lavacrete. The fact that the machine meets the existing dimension requirements would ease a lot the process of incorporating this kind of technology to such project.

Synthesis

Many of the difficulties that Brazil is facing today can be solved by some changes in the construction industry. At present day, there is a lot of money invested on improving the living situation of the lower-class citizens in Brazil. 3D printing could be a possible tool to rely on because it could reduce material costs, reduce worker's wages costs, while also increasing construction production. The Vulcan 2 is a technology that has already been tested for similar purposes and has proven to efficiently serve its goal. As shown along this research, 3D printing technologies like the Vulcan 2 can easily reduce the overall costs without affecting the quality of the end result.

Since the Vulcan 2 meets the requirements for the Minha Casa Minha Vida Project, we could implement the machine directly to the project without major structural changes. This tool could be the final step needed to push the project towards success. This project has good ideas but the implementation of this ideas is taking more time than expected. Using a 3D printer for the construction would ease the time lost in this process, but ultimately reduce construction and materials costs alleviating the budget.

3D printing were to be involved in Brazil housing solutions, Brazil might be able to ensure affordable prices on housing to those who are living in substandard conditions. Although it would be a big change in the construction industry, the change might be needed as soon as possible. Minha Casa Minha Vida is a project that contains certain good aspects but implementing more innovative technology and adding an even larger plan could exponentially increase it impact. If the Minha Casa Minha Vida projects are maintained but using 3D printers the project's scope could be wider and cover more than just one of the problems Brazil has at the time. After showing that there is a problem in the existing housing project of trying to reach the

segment with the most housing needs, 3D printing could also serve as the tool to lower cost of construction so there more chances of housing those who need it the most.

If we apply Robinson (1983) variables for success to our proposed technology the most critical issue would be retraining the workforce to use the 3D printing equipment. This could be solved by partnering with ICON to guarantee the correct training and support for the workforce. Additionally, this technology requires less overall capital investment in each specific infrastructure project. ICON technology aids in lowering the human capital expense of the project, assuming salaries per worker per day of the workforce are kept constant, by increasing the productivity of each individual given that, as previously mentioned, 4-6 workers could potentially finish one household in one day. Furthermore, the risk of overestimating the amount of materials required for each building is eliminated and therefore, there are, on average, reduced costs on materials. Based on the above, it is evident that 3D printing construction successfully leverages the variables proposed by Robinson in order to achieve its purpose of improving the existing construction practices and helping fix the current housing issues.

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