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University of Applied Sciences

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Additive Manufacturing as A Solution For Sustainable Emergency Housing.

Master's Thesis

Name of the Study Program

Construction and Real Estate Management

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from

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Date:

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Acknowledgments

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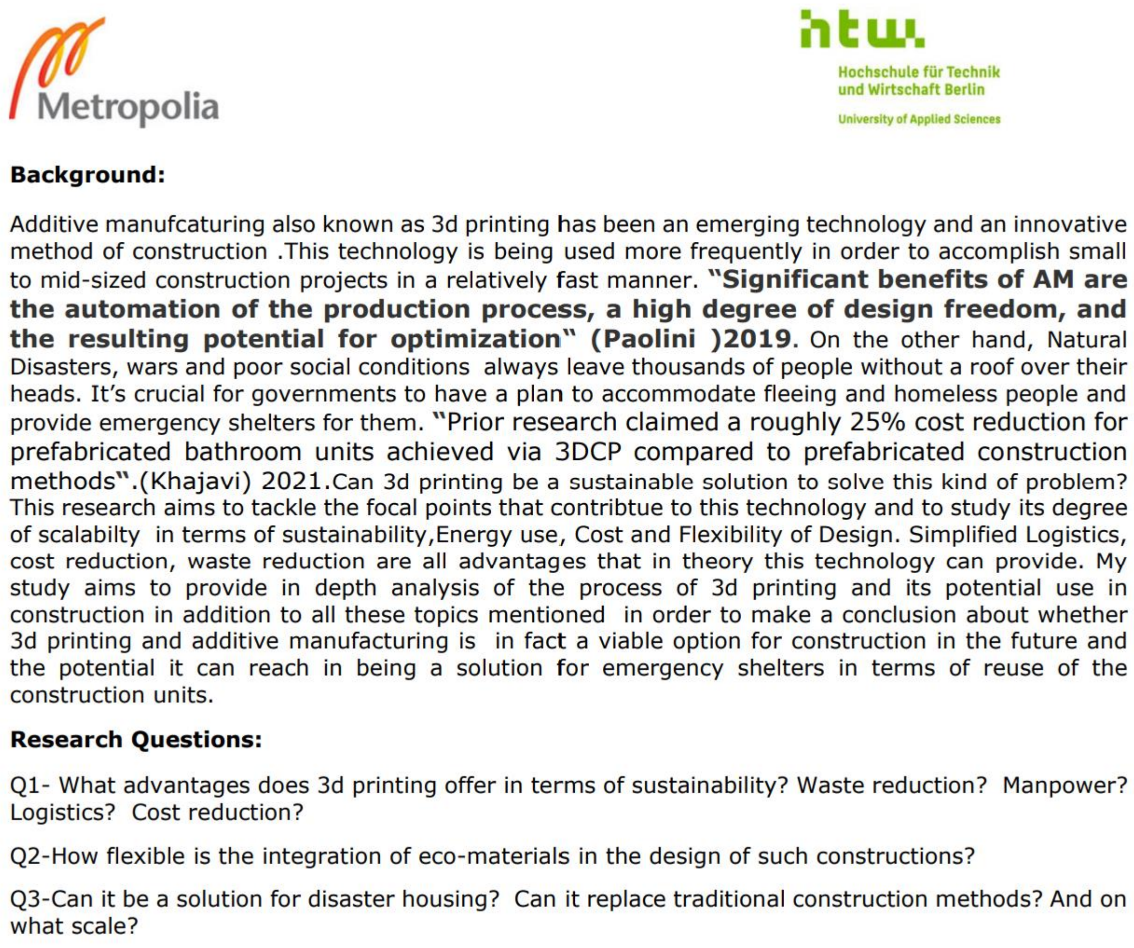
Berlin 07.07.2023
Charbel Kortbany



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Background:

Additive manufcaturing also known as 3d printing has been an emerging technology and an innovative method of construction .This technology is being used more frequently in order to accomplish small to mid-sized construction projects in a relatively fast manner. **"Significant benefits of AM are the automation of the production process, a high degree of design freedom, and the resulting potential for optimization" (Paolini)2019**. On the other hand, Natural Disasters, wars and poor social conditions always leave thousands of people without a roof over their heads. It's crucial for governments to have a plan to accommodate fleeing and homeless people and provide emergency shelters for them. "Prior research claimed a roughly 25% cost reduction for prefabricated bathroom units achieved via 3DCP compared to prefabricated construction methods".(Khajavi) 2021.Can 3d printing be a sustainable solution to solve this kind of problem? This research aims to tackle the focal points that contribtue to this technology and to study its degree of scalabilty in terms of sustainability,Energy use, Cost and Flexibility of Design. Simplified Logistics, cost reduction, waste reduction are all advantages that in theory this technology can provide. My study aims to provide in depth analysis of the process of 3d printing and its potential use in construction in addition to all these topics mentioned in order to make a conclusion about whether 3d printing and additive manufacturing is in fact a viable option for construction in the future and the potential it can reach in being a solution for emergency shelters in terms of reuse of the construction units.

Research Questions:

Q1- What advantages does 3d printing offer in terms of sustainability? Waste reduction? Manpower? Logistics? Cost reduction?

Q2-How flexible is the integration of eco-materials in the design of such constructions?

Q3-Can it be a solution for disaster housing? Can it replace traditional construction methods? And on what scale?

Conceptual Formulation

Submission date 30.06.2022

Master Thesis for Mr. Charbel Kortbany

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Abstract

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This thesis aims to investigate the potential of additive manufacturing processes as a sustainable solution to emergency housing and the shelter and displacement problem. The research, which took the MENA region as a theoretical example, being the region with the most displacement ,begins with a thorough review of the current shelter and displacement situation in affected regions, examining the roles played by local governments, markets, and citizens. Through the use of SWOT matrices, this study analyzes how additive manufacturing can provide viable and sustainable solutions for emergency housing in the affected areas. Furthermore, the research includes a shelter simulation, featuring time and cost analysis for three different construction methods and materials, facilitating a comprehensive comparison, of how Additive Manufacturing offers advantages on waste and labor cost reduction compared to conventional methods. Additionally, four case studies are presented, highlighting the application of additive manufacturing technology and its comparison to traditional sheltering methods. These case studies serve as evidence of the gradual availability of additive manufacturing capabilities to the general public. The investigation concludes that concrete printing technologies hold potential as a reliable sheltering solution for the MENA region. However, further testing and field application of this technology in the region is necessary to establish it as a viable alternative to address the complexities of the shelter and displacement issue, despite the considerable potential offered by advanced technologies.

Keywords:Additive Manufacturing,3DPC,Shelter, Social HousingD isplacement,Emergency Housing.

Contents

List of Abbreviations

AI: Artificial Intelligence

AM: Additive Manufacturing

BIM: Building Information Modeling

CAD: Computer-Aided Design

CC: Contour Crafting

FDM: Fused deposition modeling

MENA: Middle East and North Africa.

NGO: Non-Governmental Organization

SLM: Selective laser melting

Definitions

DBMS:	Database management system. Software for maintaining, querying, and updating data and metadata in a database.
ORM:	Object-relational mapping. The set of rules for mapping objects in a programming language to records in a relational database, and vice versa.

3DCP: Three-dimensional Concrete Printing.

STL: Commonly used for 3D printing, electronic file format is short for "stereolithography". This format contains only information about the triangulated geometry of an object, leaving out other properties.

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1 Introduction

1.1 1.1Project Aim

This Master's thesis presents the findings of a research project conducted by Charbel Kortbany as part of the joint master's program at HTW Berlin, Germany, and Metropolia University of Applied Sciences, Helsinki, Finland. The primary focus of this research is to assess the viability of Additive Manufacturing (AM) as a scalable solution in the construction industry, particularly for emergency housing and post-disaster sheltering. The research investigates AM's potential as a rapid construction method and its ability to address the challenges associated with shelter provision. The study aims to address the following research questions: (1) What is additive manufacturing in the construction industry, and how does it compare to conventional construction methods in terms of advantages? (2) To what extent can AM serve as a flexible short-term and long-term housing solution, specifically for emergency housing? (3) Do additive manufacturing shelters offer a viable alternative to conventional shelters for displaced populations in cost and time to build?

This research project is situated within the practical and theoretical context of the adoption of AM in the construction industry, with a specific focus on shelter solutions in the MENA region. The MENA region faces significant challenges in providing adequate quality shelters for its displaced population, which in turn exacerbates problems and complications for both the host countries and the displaced individuals. Meanwhile, the potential of AM in construction remains largely unexplored, and its numerous advantages in this sector are often underestimated. This paper aims to contribute to the development of a comprehensive conceptual framework that elucidates the application of additive manufacturing in construction and explores opportunities for optimizing its use in terms of materials, efficiency, and scalability. By leveraging the benefits offered by this technology, this study seeks to determine whether the construction industry can rely on AM to construct safe, sustainable, and habitable emergency housing for both short-term and long-term purposes. Additionally, this paper aims to provide an accessible explanation of additive manufacturing in construction for readers who are unfamiliar with the technology, facilitating a better understanding of its implications and potential synergies with other concepts. The research will contain comparative scenarios study, tackling cost and time analysis taken from 3 scenarios simulation for a shelter design made by the researcher, in order to answer the questions of this research.

1.2 Research Objectives:

The research aims to achieve the following objectives:

1. To establish a comprehensive conceptual foundation for readers to understand the concepts of Additive Manufacturing (AM) in the context of construction and develop a robust conceptual framework.

2. To serve as a catalyst for further research in the field of AM applied to shelter projects and social housing, by providing a starting point and generating interest in exploring the subject further.

3. To facilitate understanding of AM in construction for individuals with limited knowledge in the field, enabling them to grasp the fundamental concepts and establish connections between AM and sustainable emergency housing.

4. To challenge the current status quo of AM technology in construction and propose innovative applications or alternative materials that can enhance its significance and adoption within the industry.

5. To evaluate existing shelter methods, identify their limitations, and explore how AM can address these shortcomings by providing improved solutions.

6. To develop a time and cost model for 3D-printed shelters and compare it with the costs associated with conventional construction methods, providing valuable insights into the economic feasibility of AM in shelter projects.

By accomplishing these objectives, the research endeavors to contribute to the advancement and wider adoption of AM technology in the construction industry, particularly in the realm of emergency housing and post-disaster sheltering.

1.3 Background of the Study

In recent times, specifically in the middle east, natural disasters and armed conflicts have caused millions of humans to be displaced internally and to neighboring countries, where often they are left without a proper shelter that provide them with the minimum human needs in terms of security and shelter. Due to this displacement, they often must face severe climate conditions and a lot of them, without the basic need of a proper shelter will not settle and integrate in their new environment which often lead to other kind of problems for all parties involved.

On the other hand, there has been an increasing need for eco-friendly solutions due to the energy crises and greenhouse gas emissions caused by technological advancements aimed at making human life easier.

Around 30% to 40% of the world's energy consumption is attributed to buildings, resulting in approximately 30% of global CO2 emissions. In light of the world's shift towards sustainable and energy-efficient solutions, 3D printing presents an environmentally friendly building technique that eliminates a substantial amount of energy-consuming and CO2 emitting processes. Additive manufacturing offers design flexibility in construction, utilizing almost any material. However, certain treatments are necessary to prepare materials that are pumpable and printable while offering the desired structural behavior.

The design of buildings and their elements is critical in determining how much energy is being consumed in the built environment for most building techniques. By designing buildings that comply with climatic conditions and have lower energy demand, they can passively achieve thermal comfort for their occupants. In addition, Lower or even zero-energy buildings can be accomplished through the implementation of supportive passive and renewable energy systems.[1]

The potential to completely change and progress in the construction sector, particularly in social housing, can be found in 3d printing. The technology allows for rapid and cost-effective production of building components, including walls, floors, and roofs, which can be customized to suit specific requirements. This can result in faster and more efficient construction processes, reducing the time and resources needed to build social housing units. Additionally, 3D printing can also create unique and innovative designs that are not possible with traditional construction methods, allowing for greater flexibility and creativity in social housing design. With it’s non-stop development, this technology could potentially provide a solution to the shortage of affordable housing in many countries, particularly in urban areas, and help to address issues of homelessness and poverty.[2]

1.4 Methodology

The focus of this research is to evaluate the potential deployment and utilization of Additive Manufacturing (AM) technologies for sustainable emergency housing solutions for the displaced.The study will take the MENA region as a base example ,being the area with the most displaced people in the world. Qualitative data will be analyzed, and a critical assessment will be conducted to determine if the technology is ready for use. Technical aspects of AM procedures will be the primary focus, with a brief exploration of economic and sociological implications. To initiate the study, the research will begin with a literature review on emergency housing and refugee camps, utilizing the latest regional reports provided by relevant organizations. News media articles will also be analyzed to provide updated insights into displacement ,specifically in the Middle East, taking into account the effects of war and natural catastrophes implying the need for proper and fast shelter solutions. The problems with existing sheltering solutions will be analyzed and the need of alternative solutions highlighted.

A comprehensive literature review will also be conducted to provide an explanation and framework of automation technologies and additive manufacturing in construction. Key findings will be summarized using SWOT matrices, and strategies for the potential possible deployment of the technology in the region will be determined.

To provide a solid understanding of the research topic, four case studies of projects that have utilized 3D printing equipment will be presented in order to answer the study questions and provide a benchmark to compare costs and time.. The study will focus on the parameters of the research aims and seek solutions to a challenging local issue.

A BIM model of a shelter will be developed and used to compare between 3DCP and other types of shelters. The comparison will tackle resources, time, and cost in such a scenario, utilizing data provided by the Bim model like the quantity of materials needed as well as data provided by research, and conclude how a 3D printed shelter measure up to conventional sheltering methods.

The project utilizes a descriptive research method to gain an understanding of the current state of technology, by examining existing literature and publications, as well as Scenario Simulation method to obtain general comparative data and build findings based on it. After conducting an in-depth analysis of the available content, the researcher structured the main ideas to enhance the clarity of the concepts. The researcher then provided their input by linking the obtained concepts with prior knowledge.

As this project serves as a conceptual framework, a thorough understanding of prefabrication fundamentals was necessary. Subsequently, the researcher developed their definitions and relationships based on industrialized building terminologies to relate them to Emergency housing and 3d printing in the sector of construction. The researcher introduced AM literature and established relationships with prior concepts after presenting the theory.

After explaining how the different terminologies are related, the researcher exposed various construction techniques which enabled the creation of a basic framework. This framework presented and evaluated manufacturing technologies, with special attention paid to 3D printing.

2 Literature Review:

In this chapter, a literature review concerning the need for shelters and emergency housing in the middle east will be presented. Figures will be taken from trusted sources like reports made by international organizations and non-governmental parties that are specialized in the field of refugees on the number of displaced in that region because of conflicts and/or natural disasters. A comprehensive definition of types of shelters and types of responses in the case of emergencies will also be presented. Then, a detailed review of Concrete printing technology, different methods, know-how and use in the construction sector will be developed based on existing literature.

2.1 The Human Right to Shelter

The Universal Declaration of Human Rights' Article 25 was the first to recognize the right to adequate housing. The concept of "the right to adequate housing" is applicable to all those impacted, including men, women, boys, and girls, and applies to all stages of displacement, including before, during, and after displacement. The affordability of housing, the accessibility of services, the security of tenure, the cultural appropriateness, the accessibility, the location, the materials, the facilities, and the infrastructure all play a role in how adequate it is.UNHCR acknowledges the right of refugees and other individuals under its care to appropriate shelter, which provides protection from harsh weather, sufficient living and storage space, privacy, comfort, and emotional support. A safe and habitable covered area that safeguards against harsh weather conditions while also providing space for personal belongings and emotional support is considered a shelter. Shelter programs may comprise various solutions, such as tents, cash assistance, plastic sheeting, and shelter kits. The availability of suitable shelter is a critical factor in determining living conditions and may be a significant expense. However, depending on the emergency context, the nature of the required shelter, materials, design, construction, and duration may differ.

For instance, shelter requirements in urban areas may differ from those in rural areas. Thus, the most effective way to meet emergency shelter needs is to utilize materials and solutions used by the local population. Shelter solutions must be tailored to the region's particular climate, cultural norms, technical capabilities, and construction materials.[3]

Rarely is it possible to provide a single shelter solution that satisfies the demands of all displaced populations. Therefore, best practice calls for offering a variety of choices, including financial aid, rental help, building supplies, temporary housing, shelter kits, plastic sheeting, tents, and more, whenever possible.[4]

2.2 Displacement:

According to the report made by the AGM (2021), there are the most refugees in proportion to the population in Lebanon. Turkey has the largest number of refugees. Colombia, Syria, Congo, and Iraq have the most people who have fled within their own country. It is significant that the majority (61%) have fled natural disasters. Of the total number of refugees in the world, Finland has 0.04% and the EU has 5.4%. Two-thirds of all refugees in the world come from Afghanistan, South Sudan, Syria, Myanmar and Somalia. The largest recipient countries are Turkey, Pakistan, Uganda, and Sudan. Four out of five refugees stay in their home country's neighboring country.[5] Around three million refugees were able to return to their home region in 2018, however, there are still more people escaping than people returning. More than half of the refugees are children, but it is worrying that the number is increasing. There are almost the same number of men and women among the refugees. The figures are based on UNHCR data. Migration and international politics related to disasters or conflicts are colored by various intersecting values and interests.

2.2.1 From Natural Disasters:

The world is expected to witness a significant increase in natural disasters leading to massive displacement of people, which will alter the current perception of forcibly displaced individuals, such as refugees and internally displaced persons (IDPs), who are uprooted due to conflict and persecution. While most of the displaced individuals will remain within their country, a considerable number will cross internationally recognized borders, particularly as island states submerge. [6]A Christian Aid report in 2007 projected that by 2050, climate change-related phenomena like floods, hurricanes, and droughts will permanently displace 250 million individuals, though the exact numbers may vary. According to the United Nations and the Internal Displacement Monitoring Centre (IDMC), sudden-onset natural disasters, including climate change-associated catastrophes, uprooted about 36 million people in 2008, of which 20 million were displaced by climate change-induced disasters. Additionally, tens of millions more people may have been displaced by slow-onset environmental issues like drought, desertification, rising sea levels, deforestation, and land degradation in 2008. While migration from such disasters has been considered voluntary traditionally, it is now being viewed as forced, and international definitions of forced migrants and systems of protection for them may need to expand to accommodate the various migration patterns arising.[7]

The first concerns following a disaster are protecting lives and providing for basic needs. A wider spectrum of rights must be addressed in the next weeks and months. Evacuations, relocations, protection against violence, camp security, and the detonation of landmines are all included in the first group of protection activities. Access to humanitarian help and the equitable provision of essential commodities and services fall under the second category. Long-term housing, educational chances, compensation or restitution for lost property, and job opportunities are all included in the third category. The fourth category includes political liberties, family reunions, voting rights, freedom of expression, freedom of assembly, and documentation. In order to ensure that all of the victims' needs are satisfied, the Guidelines emphasize that humanitarian assistance must be founded on a human rights framework. Failure to do so could lead to violations of human rights. People who are forced across borders by environmental disasters also require protection, but there is currently no specific normative framework that addresses their needs, and neither the Operational Guidelines nor the Guiding Principles apply to their case.[8]

Data collection on disaster displacement has proven challenging for local, national, and humanitarian aid organizations due to the presence of conflict and violence in the MENA area. Due to this, there are large knowledge gaps regarding the scope, nature, effects, and duration of disaster displacement. As a result, both the total number of IDPs related to disasters and the estimates of new displacements are extremely conservative. Despite these restrictions, the data indicates that during the previous ten years, there were nearly 1.5 million new disaster-related displacements. Due to an increase in floods and general improvements in data collecting and monitoring of disaster relocation, the aggregate numbers are rising. Weather-related events, particularly floods, were responsible for most of the disaster displacement during the last decade, with storms and earthquakes causing fewer but still significant numbers of displacements in some countries of the region. (*See Fig.1*)

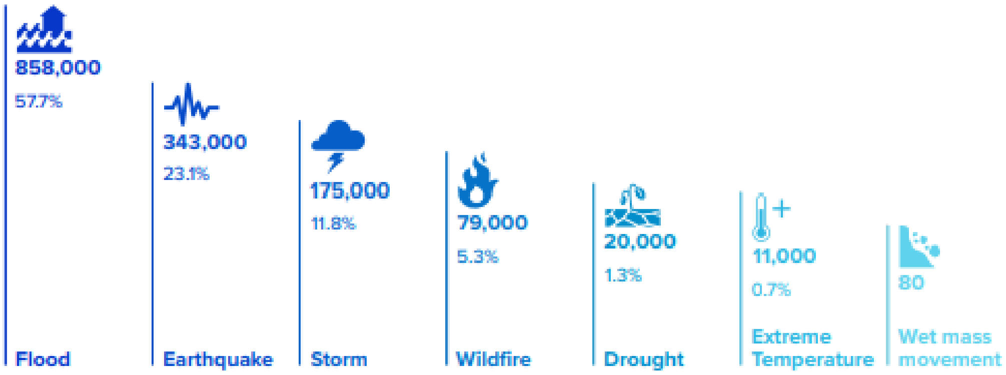


Figure 1:New Disasters Displacements in MENA, by type (2010-2019)[6]

The most recent 7.8 magnitude Earthquake that struck Turkey and Syria on February 6, 2023, has leftaroundd 23 million people, including 1.4 million children residing in the affected regions of Turkey and Syria, as stated by the WHO. The earthquake was followed by numerous aftershocks and a second significant earthquake with a magnitude of 7.5 struck the region after 9 hours, causing severe damage and destruction to already damaged buildings.

The latest data reveals that the death toll has reached 38,044, while 108,068 individuals have been reported injured. The surveys conducted indicate that 56,080 buildings across 10 provinces have either collapsed or have been severely damaged. Due to the risk of aftershocks, people are unable to return to their houses and are forced to stay outdoors in the cold and rainy weather. The Ministry of Infrastructure and Transport has reported that 237,000 individuals have been evacuated from the disaster zone. Significant power and water cuts are still being observed in remote areas.

These Figures show the magnitude of the damage caused by natural disasters and how it can leave affected people without shelter.[9]

2.2.2 From Armed Conflicts:

Between 2010 and 2019, conflict and violence accounted for the majority of internal displacement in the MENA region, accounting for an average of 2.9 million new displacements annually as opposed to only 149,000 caused by disasters. By the end of 2019, 12.4 million people had been uprooted by conflict and violence in the area as a result of a number of circumstances, armed conflict, infrastructure and housing devastation, the presence of explosive relics of war, insecurity, and a lack of essential services. However, the Arab Spring marked a significant shift in conflict and displacement patterns in the region. While the risk of displacement is deeply rooted in social, economic, and political factors that go back decades or even centuries, the Arab Spring. Syria, Iraq, Yemen, and Libya are the most affected countries, accounting for more than a third of new conflict displacements globally over the last decade *(See Fig.2).*

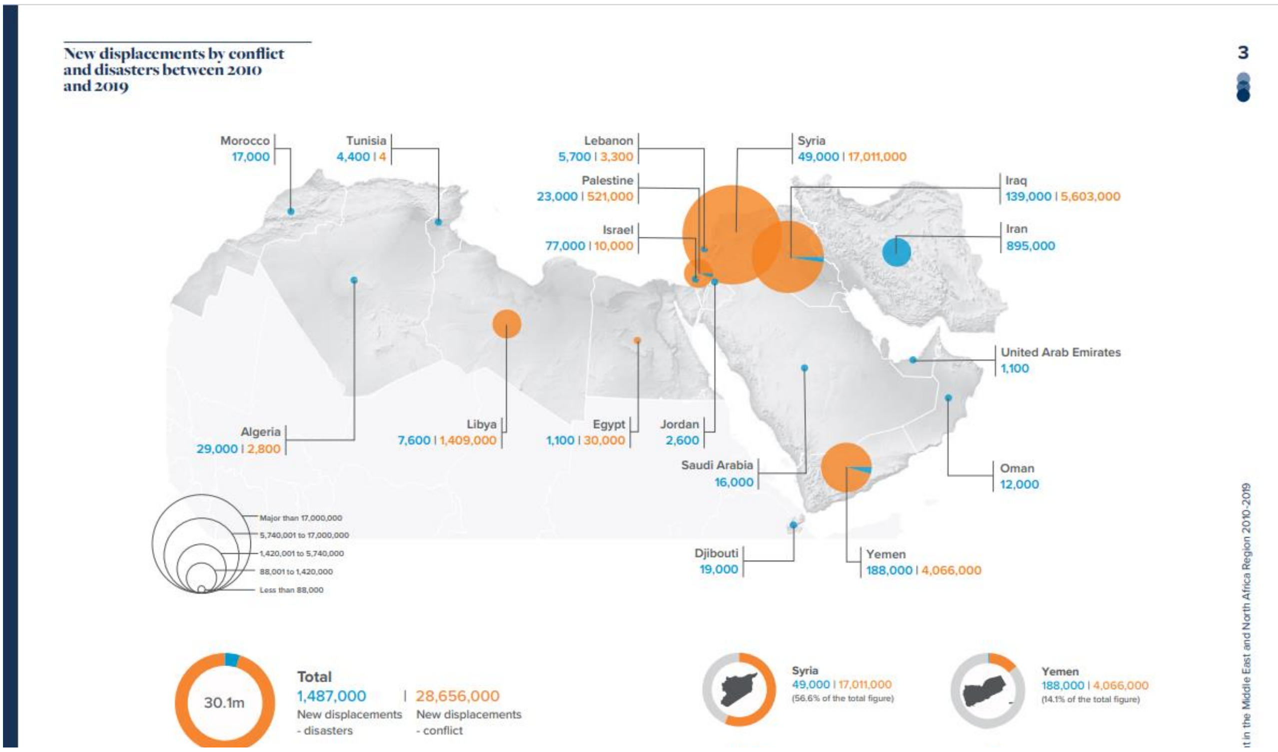


Figure 2:Displacements in the MENA caused by natural disasters and armed conflicts between 2010-2019 [6]

National crises have also had a spillover effect on neighboring countries, with Jordan and Lebanon seeing an increase in their combined refugee population of at least 1.3 million after the Syrian conflict broke out.[8] “Some families claimed to have abandoned their luggage during the flight since it was hard to retrieve their personal items. Many people no longer communicate with their family members. Many of them want to return so they can have normal lives and once more provide their kids access to school. The ICRC's head of delegation in Syria, Marianne Gasser, describes the hardships faced by families displaced by war, including fleeing with urgency and chaos, losing possessions, and being separated from loved ones. Despite these difficulties, those affected by displacement still strive for a normal life and to provide for their children.[10] Providing reliable shelter is one of the basic primary needs to get these people back on track to regain a part of their lost lives.

2.3 Post-Disaster Housing:

After a natural disaster, or a war, housing represents the biggest part of loss and is naturally the element that holds the most damage in the general impact of said disaster on the economy. Socially, economically and environmentally sustainable development goals will play an even bigger role in humanitarian construction in the future and will require new solutions. Large international organizations, such as the UN refugee agency UNHCR, the Red Cross, and the international migration organization IOM, are constantly working to improve the living conditions of refugees, and have published various guidelines, manuals,s and catalogs to define the boundary conditions for humanitarian housing construction. Despite this, there is no uniform, international standards or even a consistent vocabulary for humanitarian residential construction. Even finding a suitable umbrella term that describes the topic is difficult, as the interpretation of concepts varies depending on the entity.

2.3.1 Definition and characteristics:

The shelter is a fundamental human need and an essential factor for survival and resilience during most crises. The right to adequate housing, as stipulated in human rights laws, encompasses not only the availability of space and protection but also the proper sitting of settlements and access to services. The shelter is often the most valuable asset and highest living expense for individuals, indicating its importance in promoting economic well-being and securing livelihoods.[11] Typically, affected households are responsible for the majority of shelter solutions in many contexts. In disaster response efforts, providing emergency shelter and performing critical rehabilitation are crucial humanitarian activities to prevent excessive mortality and morbidity. Shelter not only enables survival, but it also promotes safety, protection, and resistance to ill health and disease while sustaining family and community life and restoring affected populations' dignity.[10] Furthermore, shelter plays a crucial role in reducing vulnerability and building communities' resilience. Considering shelter and settlement as a whole, safe settlements are necessary to provide crisis-affected communities with protected and healthy living spaces and environments that preserve the groups, families, and individuals' privacy and dignity.[11]

More than just a physical building with enough room and conditions constitutes shelter. The only standard for shelter interventions shouldn't be building upgrades, and the same goes for the shelter itself. Settlements shouldn't be thought of as secure locations with shelters and essential amenities. Instead, settlements ought to be viewed as livable communities with a stable socioeconomic environment. Settlements and shelter must be integrated from the beginning, with the physical site being just as significant as the shelter itself. Settlements and housing are essential for the post-disaster rebuilding process because they offer people safety, security, dignity, economic well-being, and stable sources of income.[11] The distribution of tents and tarps should not be the only component of humanitarian shelter and settlement operations. People always require refuge in emergencies, but they may not always want or need physical shelter. Humanitarian shelter and settlement initiatives should instead go beyond simply providing a commodity or financial subsidy for shelter and instead address people's housing needs holistically. Types of Post-Disaster Housing:

2.3.2 Emergency Shelter:

Emergency shelters are established as short-term housing facilities to offer immediate assistance to individuals and families who have been forced out of their homes as a result of a crisis or disaster[3]. These shelters are commonly used by people who have been evacuated from their homes or lost in emergencies such as earthquakes, hurricanes, wildfires, and other similar events. The size and configuration of emergency shelters may vary, ranging from extensive community centers and schools to smaller, temporary structures such as trailers and tents. These facilities generally offer fundamental necessities, such as food, water, sanitation, and medical services.[4]

2.3.3 Transitional Shelter or T-shelter

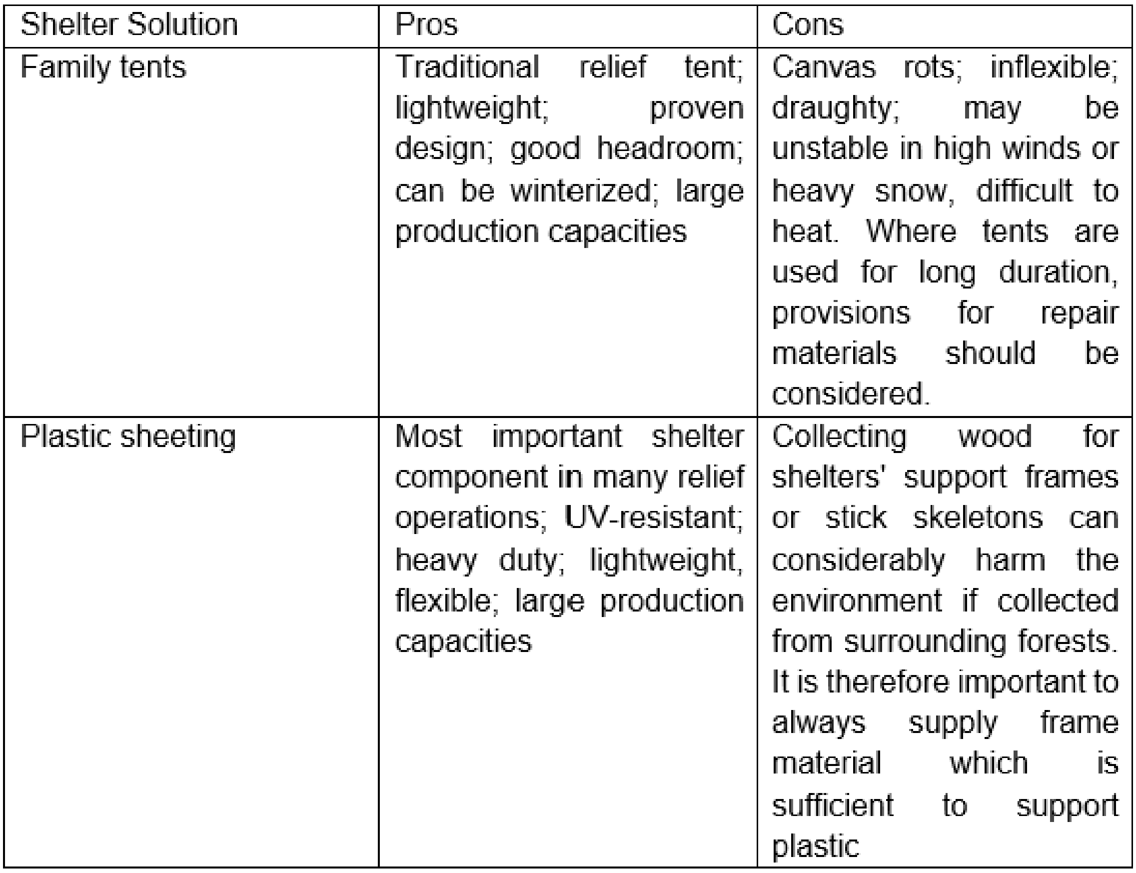
Household shelters that are quickly built using materials that can be modified, repurposed, or moved from temporary to permanent places are known as transitional shelters.[9] They are intended to help those affected by disasters as they move from the emergency stage to the recovery stage. These shelters adhere to Sphere requirements for shelter, water supply, sanitation, and hygiene and are made to be more durable than emergency shelters. They are constructed with materials that can be used for permanent housing and are intended to last for between six and twenty-four months.[11]. These shelters can be upgraded to become permanent structures or disassembled for transport and reuse in the construction of program participants' permanent housing. The construction techniques used in transitional shelters also aim to enhance their resistance to natural hazards, such as through the use of more durable wooden structures or steel frame structures. The goal is to support the affected population's resourcefulness and self-management in rebuilding their communities following a disaster.

2.3.4 Permanent Housing

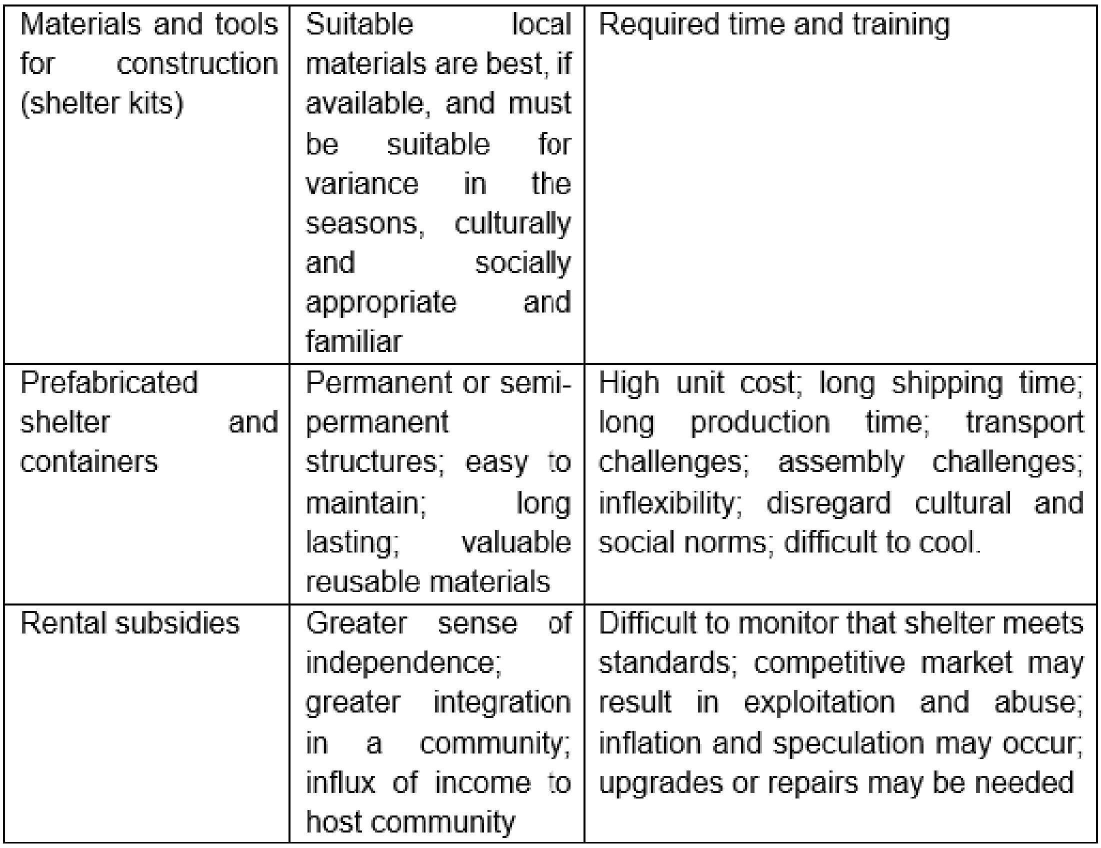
Permanent housing offers a long-term solution for shelter, and it requires a secure land tenure to ensure that the structures are not easily relocated. Village or urban planning is also crucial for permanent housing projects.[11] Concrete frame with brick or block infill has been a common approach to building permanent housing, but it may not be the only solution. Successful housing design takes into account the climate, cultural appropriateness, and natural hazards of the area. Therefore, different regions may require different approaches to permanent housing design. Permanent housing must conform to national housing standards and building codes. It should remain intact and inhabitable for a minimum of 10 years and be constructed using durable materials and techniques.[11] Permanent housing design should also integrate construction techniques that are resistant to known natural hazards. This includes measures such as earthquake-resistant structures, hurricane-resistant roofs, and flood-resistant foundations, depending on the natural hazards present in the region. By taking into account these factors, permanent housing can provide a safe and sustainable solution for long-term shelter needs.

2.4 Existing Solutions for Emergency and Social Housing:

The existing solutions for emergency and social housing range from providing family tents, to rental subsidies. These solutions are various and depend on the situation at hand and the type of shelter needed. They all range from short-term shelter solutions to long-term shelter solutions and permanent solutions. All of the solutions have their advantages that they provide as well as some disadvantages that are going to be listed in the table below.



Shelter Solution	Pros	Cons
Family tents	Traditional relief tent; lightweight; proven design; good headroom; can be winterized; large production capacities	Canvas rots; inflexible; draughty; may be unstable in high winds or heavy snow, difficult to heat. Where tents are used for long duration, provisions for repair materials should be considered.
Plastic sheeting	Most important shelter component in many relief operations; UV-resistant; heavy duty; lightweight, flexible; large production capacities	Collecting wood for shelters' support frames or stick skeletons can considerably harm the environment if collected from surrounding forests. It is therefore important to always supply frame material which is sufficient to support plastic



Materials and tools for construction (shelter kits)	Suitable local materials are best, if available, and must be suitable for variance in the seasons, culturally and socially appropriate and familiar	Required time and training
Prefabricated shelter and containers	Permanent or semi-permanent structures; easy to maintain; long lasting; valuable reusable materials	High unit cost; long shipping time; long production time; transport challenges; assembly challenges; inflexibility; disregard cultural and social norms; difficult to cool.
Rental subsidies	Greater sense of independence; greater integration in a community; influx of income to host community	Difficult to monitor that shelter meets standards; competitive market may result in exploitation and abuse; inflation and speculation may occur; upgrades or repairs may be needed

Table 1: Existing Shelter Solutions Pros and Cons.[3]

Analysis of these solutions:

In a brief analysis of the table above, a conclusion can be made that post-disaster shelter solutions face a lot of difficulties including financial, logistics, management, safety concerns, health concerns, etc. Prefabricated Shelter and containers provide easy maintenance, are long-lasting, and provide permanent or semi-permanent structures, but on the other hand, their disadvantages are many, including high unit cost, long shipping time, long production time, transport challenges, assembly challenges, inflexibility, etc. In first reflection, additive manufacturing and 3d printing can solve thaig part of these challenges. To dive more into this I ca studies of shelter camps were taken into consideration in the coming chapters and analyzed , strengths and weaknesses of the solutions implemented in these cases were then concluded.

2.5 Shelters and Health

According to the World Health Organization (WHO), insufficient housing and overcrowding are two key contributors to the spread of illnesses with an epidemic potential that are spread through airborne droplets, skin-to-skin contact, or feces-oral routes. [12]

It goes on to say that occupational densities are a significant risk factor for a variety of respiratory disorders, including pneumonia, TB, and numerous allergies due to the higher possibility of disease transmission in crowded situations. Finally, it mentions that there is a greater danger of airborne infectious illness transmission when there is insufficient ventilation.[12]

2.6 Shelters and Security

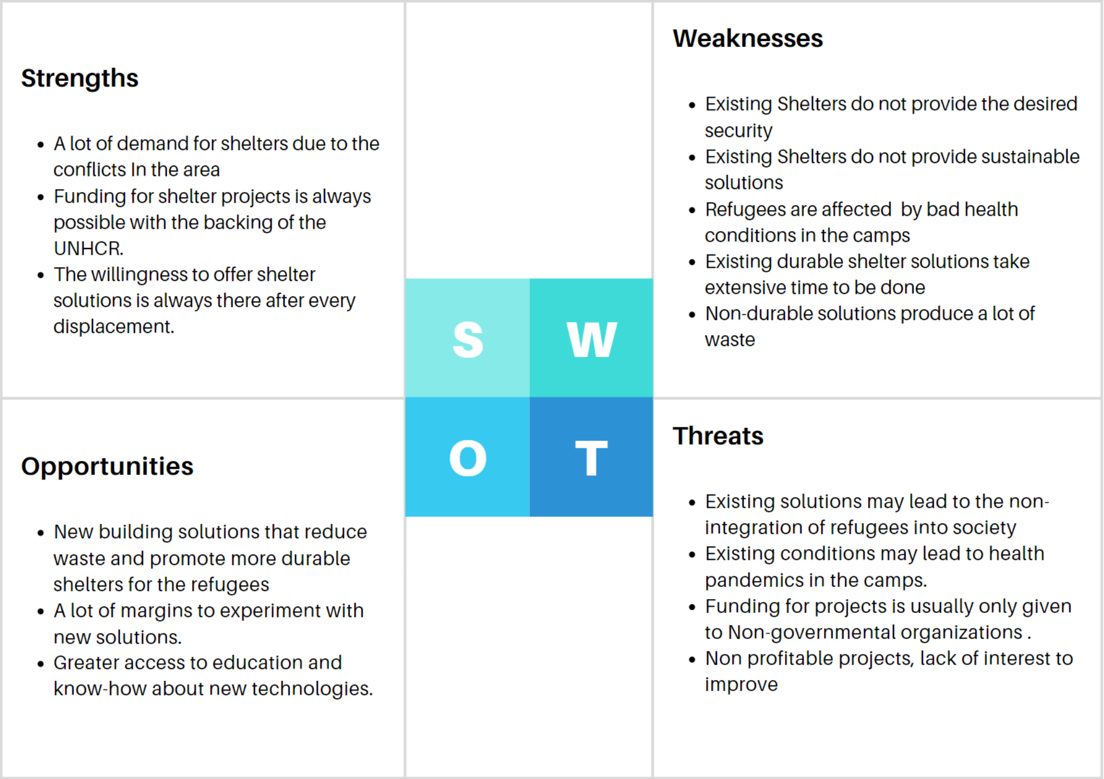
Shelters should offer sufficient security for both individual safety and the secure storage of valuables. In general, the absence of windows and doors was indicated as the main cause of feeling unsafe. Secondary causes of felt vulnerability were the brittleness of walls and particular roof kinds (plastic, chicks, mud). Burnt brick performed notably better than all other architectural typologies in terms of felt security, it should be noted. [13]

2.7 Shelters and Privacy

Shelters should offer enough privacy for residents to go about their everyday lives as they, please. According to a survey made by the UK government, The attitudes of privacy among men (75%) and women (63%) differ significantly, though. Visibility through apertures was regarded as the main cause of a lack of privacy. Similar to how security was addressed previously, the addition of windows and doors would allay these worries. Therefore, it is recommended using doors and windows that are both operable and lockable (such as timber shutters) or inherently secure .[13]

Shelter Situation in the MENA: SWOT

It could be concluded that the shelter situation in the MENA region is delicate. The existing solutions are not sufficient for the suffering displaced people to feel safe, secure or stable. On the other hand, funding and involved organisations are numerous, which make implementing change possible. A SWOT analysis of the current situation is illustrated in the table below:



Strengths

- A lot of demand for shelters due to the conflicts In the area
- Funding for shelter projects is always possible with the backing of the UNHCR.
- The willingness to offer shelter solutions is always there after every displacement.

Weaknesses

- Existing Shelters do not provide the desired security
- Existing Shelters do not provide sustainable solutions
- Refugees are affected by bad health conditions in the camps
- Existing durable shelter solutions take extensive time to be done
- Non-durable solutions produce a lot of waste

Opportunities

- New building solutions that reduce waste and promote more durable shelters for the refugees
- A lot of margins to experiment with new solutions.
- Greater access to education and know-how about new technologies.

Threats

- Existing solutions may lead to the non-integration of refugees into society
- Existing conditions may lead to health pandemics in the camps.
- Funding for projects is usually only given to Non-governmental organizations .
- Non profitable projects, lack of interest to improve

Table 2:SWOT analysis of the shelter situation in the MENA region.

2.8 Robots and Humans connection.

Additive Manufacturing in construction relies on automation and Robots to do the job of layering in order to produce the product, for this reason, in the next chapter ,a brief explanation of the evolution of robots and automation as well as the main components that makes a robot function .

Although industrial robots have historically received most of the attention in the history of robotics, applications for robots in business and personal services have grown significantly. Numerous sectors, including cleaning, laboratories, medicine, logistics, construction, and mining, as well as mobile robot platforms for search and rescue, hazardous area repairs, military, security, and entertainment, are examples of professional service applications. Applications for personal services include robots for entertainment, vacuuming, and education.

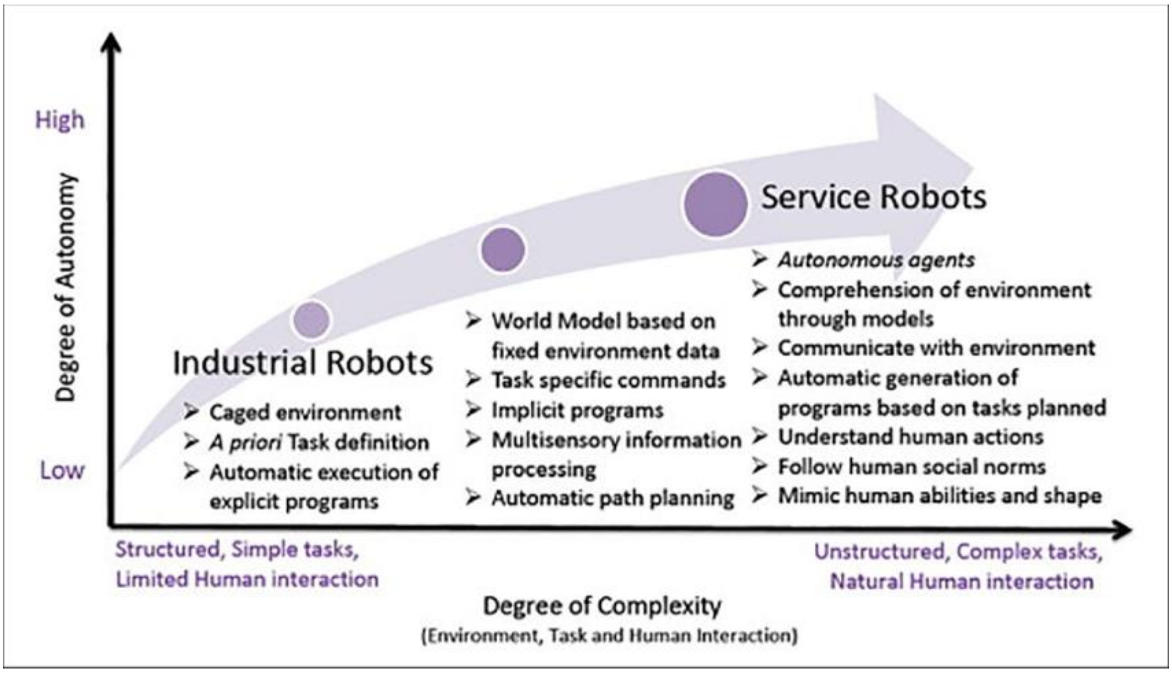


Figure 3: Robots spectrum in terms of autonomy and complexity

According to estimates, the total number of robots in the world has increased from 4.49 million in 2006 to 8.37 million in 2010,[14] with a majority being service robots.

The number of industrial robots is predicted to remain same in America, but to slightly increase in Asia, Australia, and Europe. The majority of industries that use industrial robots are those that produce metal goods, food, packaging, electronics, automobile parts, and electronics. Industrial robots are meant to move materials, parts, or devices through preprogrammed motions to execute a variety of activities. The Robotics Industries Association and the International Standards Organization have distinct definitions for these machines.Data Transmission Between Humans and Robots.

In the field of robotics, the term "core logic" is used to describe the foundational programming that controls a robot's behavior. This programming consists of the decision-making processes and algorithms that dictate the robot's response to its surroundings, as well as its interactions with humans and completion of tasks. These include of sensors, driver, operating systems.[15]In contrast, "domain logic" refers to the specific knowledge and rules that pertain to a given area of application. This can include information about the physical properties of objects the robot handles, the proper procedures for accomplishing tasks, and the safety concerns associated with working in a specific environment. Core and domain logic are both crucial components of robotics, and they must work together seamlessly to create a robot that can perform its functions effectively while maintaining safety and reliability.

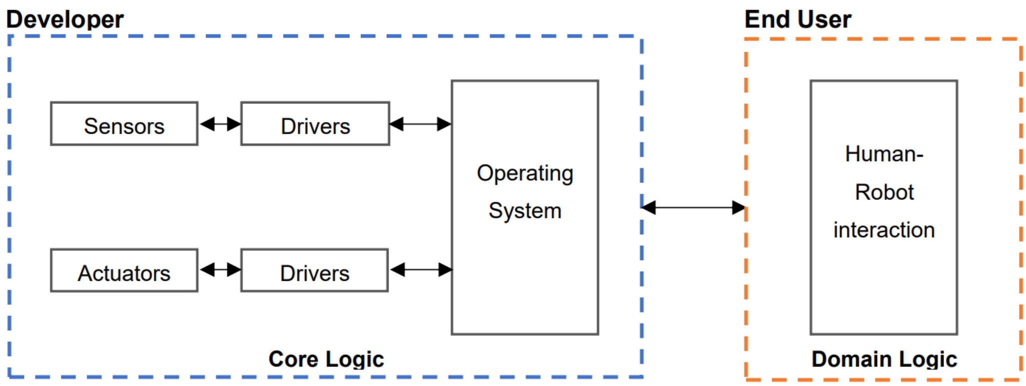


Figure 4: Relationship between Core and Domain Logics.[11]

3D Printing:

3D printing, also known as additive manufacturing, involves the layer-by-layer deposition of materials to create physical objects based on digital designs. The process requires software, hardware, and specific materials. This technology is expected to advance and has the capability to aid designing and developing prototypes, automobile , medical implants, airplane components, and even organs for human medical use.[16]

2.8.1 DFM AND SLM

Generally, Two main techniques exit and are utilized in 3D printing. In the first approach, materials are melted with a laser's help to form the different layers that make up a substance. In this field, popular processes include fused deposition modeling (FDM), selective laser melting (SLM), and selective laser sintering (SLS). The second technique uses liquid ingredients that are cured to produce the desired object. Stereolithography (STL) is a typical illustration of this technique.[13] Scott Crump, a co-founder and current chairman of Stratasys Ltd., developed fused deposition modeling (FDM) in the 1980s. Later, Fused Filament Fabrication (FFF), a technique invented by MakerBot, a company now owned by Stratasys, was created. To print a 3D model, the 3D printer is fed to the model file and uses plastic threads to construct the object. The printer's nozzle melts the filaments and deposits them in layers on top of each other. The plastic quickly hardens as it is placed on the building platform, and the layers bond together as the plastic cools, creating a solid object. The computer controls the nozzle's movement in the X, Y, and Z directions to follow the printing path created by the computer, and this process is repeated until the object is completed.[17]

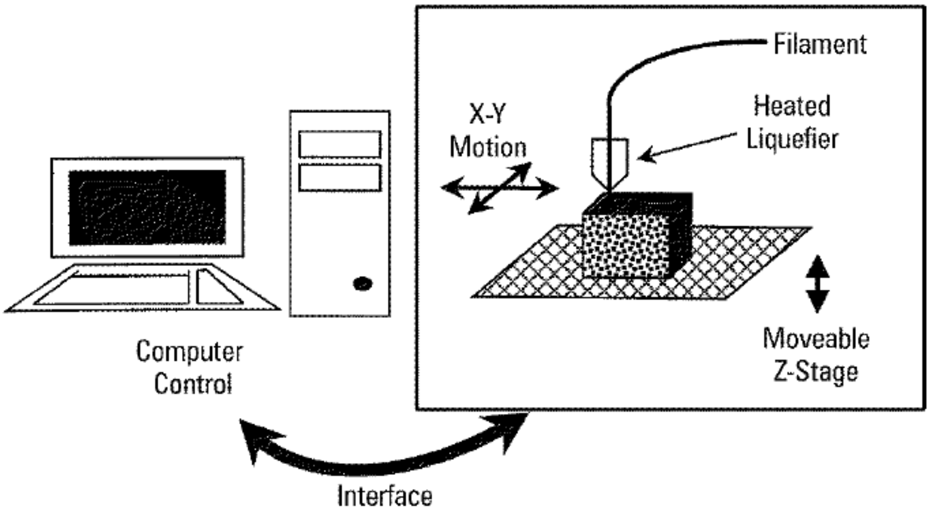


Figure 5: Relation between Computer and Machine[18]

This printing method is currently the most common of all 3D printing technologies and has been widely adopted in many industries such as medical and construction, as well as for creating prototypes for various purposes. Examples of this type of printer include Cube, Replicator, and Mojo, which are designed for inventors, hobbyists, and small business owners[17]. These printers are typically small, efficient, and user-friendly. Various materials have been optimized for this printing technique, including plastic, steel, concrete, and more. The 3D printing of concrete using these printing techniques is explained later in this thesis. [18]

2.9 Fundamentals of AM:

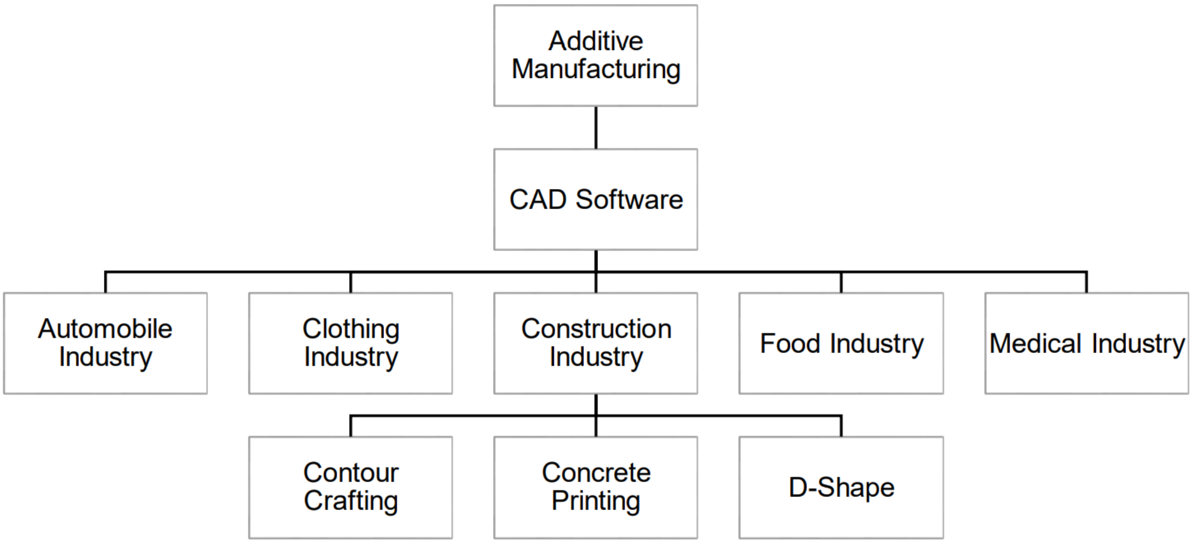


Figure 6: AM main industries[20]

Using layers of a particular material to create 3D items based on digital models is a process known as additive manufacturing, also known as rapid prototyping. [19]The utilization of AM technologies has rapidly advanced in recent years and has become a crucial tool for various applications including biomedical engineering, prototype fabrication, electronic equipment, and construction. AM has gained significant popularity and has become easily accessible, to the extent that 3D printers are now commonplace alongside computers.[19] Figure 3 provides an overview of AM application in different sectors of industry. In recent years, there has been a surge in the popularity of additive manufacturing, also known as layered or rapid manufacturing. Due to a number of variables, including

as the greater accessibility of open-source software and crucial patents that have expired, which have made the technology more affordable and accessible, manufacturers have widely adopted this novel building technique. Additive manufacturing is a 3D printing process that utilizes computer control to layer 3D printed materials, resulting in complex and intricate 3dimensional objects. The technique is known for its low environmental impact, reduced labor costs, and faster construction times, making it an attractive option for manufacturers.[19]
From micro functional parts to large-scale structures and buildings, the range of applications for additive manufacturing is vast. One specific application is concrete printing, which utilizes a mixture of concrete as the printing material. The concrete printing system comprises several components, including a concrete tank, a pumping mechanism, a printing nozzle, and a motion control system. By layering the concrete mixture, the system creates the desired 3D shape, offering numerous benefits, such as minimal material waste and the ability to produce intricate shapes that would be challenging to achieve using traditional construction techniques.[20] For a successful building product, the material used in the process must be pumpable, printable, buildable, and have the required strength to hold the required loads, resist deformation, and meet the required structural behavior.

2.10 Additive Manufacturing in Construction:

The types of additive manufacturing in the construction industry are three in principle: D-Shape, Contour Crafting, and Concrete Printing. These subjects will be tackled in the coming chapters.

2.10.1 Contour Crafting

Behrokh Khoshnevis from the University of Southern California’s Information Science Institute has been researching Contour Crafting, a building printing technology. This innovative technology has garnered interest from NASA for its potential application in constructing bases on the Moon and Mars. Following this, in 2013, NASA funded a small study at the University of Southern California to further develop the 3D printing technique used in Contour Crafting.[21] The technology itself is an additive fabrication method that leverages computer control to create accurate and smooth planners and free-form surfaces. What sets Contour Crafting apart is its use of two trowels, which act as solid planer surfaces to create surfaces that are both smooth and precise. The use of such simple tools has been an effective technique for forming materials since ancient times, and today, industrial model-making employs similar surface-shapingg knives.[21]

It is reported that Contour Crafting (CC) has significant potential for implementation in the construction industry[15]. The technology's simplicity, low cost, and ability to connect with widely available technologies make it an attractive option. Furthermore, CC can handle overhangs through compression, avoiding the potential cantilever issue. Lintels, for instance, can be added above to span the openings made by windows or doors. Figure 16 provides a graphic representation of the CC system and its fundamental parts, highlighting the connection between the digital three-dimensional model, the mixing machine, pump,the and robotic arm. (See Fig. 8)

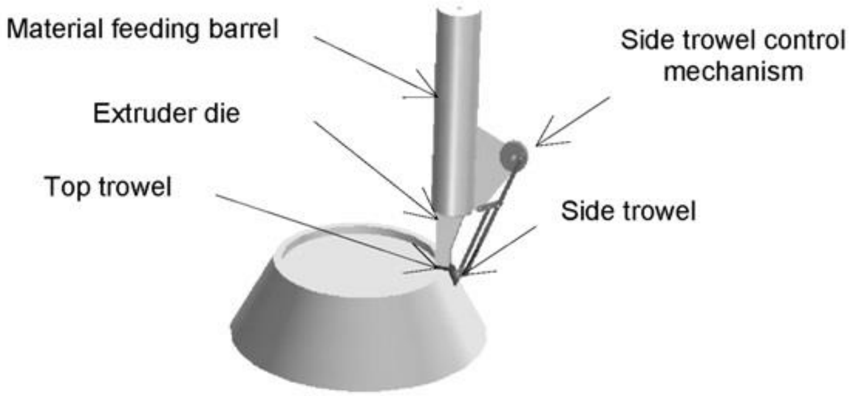


Figure 7: Contour crafting components

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2.10.2 Concrete printing

Utilizing a layer-by-layer extrusion technique, concrete printing is similar to Contour Crafting (CC) in applying the designated building material. Finding the ideal mixture to provide the necessary mechanical qualities and features is a step in the preparation of the material. The primary distinction between concrete printing and CC, however, is that the former aims to preserve three-dimensional flexibility [15]. This method necessitates the use of two building materials, one of which serves as a support framework. Please refer to section 9.1 on page 84 for more details regarding printed supports.

The printing of basic precast components is now possible thanks to a concrete printing device created by Loughborough University that can handle maximum dimensions of 5.40 meters in length ,4.40 meters width and 5.40 meters in height [15]. The system's lower deposition resolution compared to CC allows for more precision when producing complicated structures.. All of the aforementioned techniques have demonstrated their capability to construct large-sized modules. The accompanying images provide an illustration of the concrete printing process.

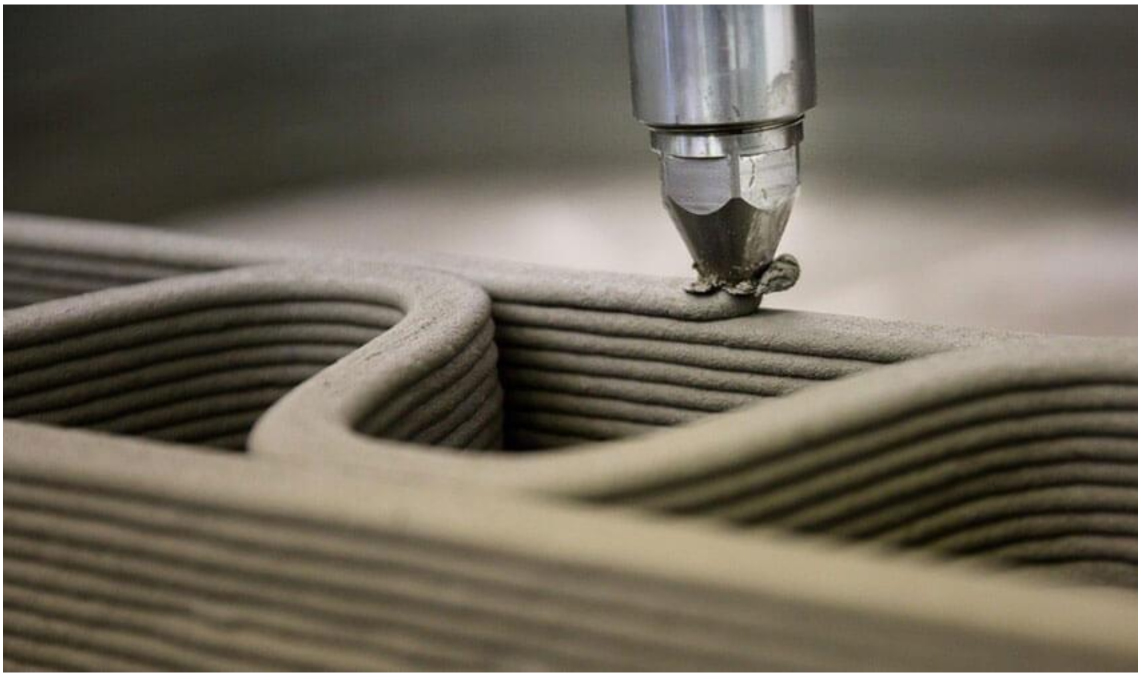


Figure 8:Concrete 3D printing using an FDM process. (Source:XtreeE)

2.10.3 D-shape

The D-Shape printing technique is essentially an enlarged version of the binder jetting (bj) process, which involves selectively depositing a binder on each layer of powder material. In this case, the powder material is a mixture of sand and magnesia-based cement that is first combined into a dry powder, then spread into layers within the 3D printer. The binder material used is a saline water solution, which is jetted or sprayed onto each layer of dry powder material, much like ink on paper in a conventional desktop inkjet printer. Upon deposition, the binding material penetrates through the powder layer, reaching the layer underneath, and this process repeats for each layer until the end of the structure is reached. The overall result is a volume of unbound powder material containing the solidified/printed part within.[22]

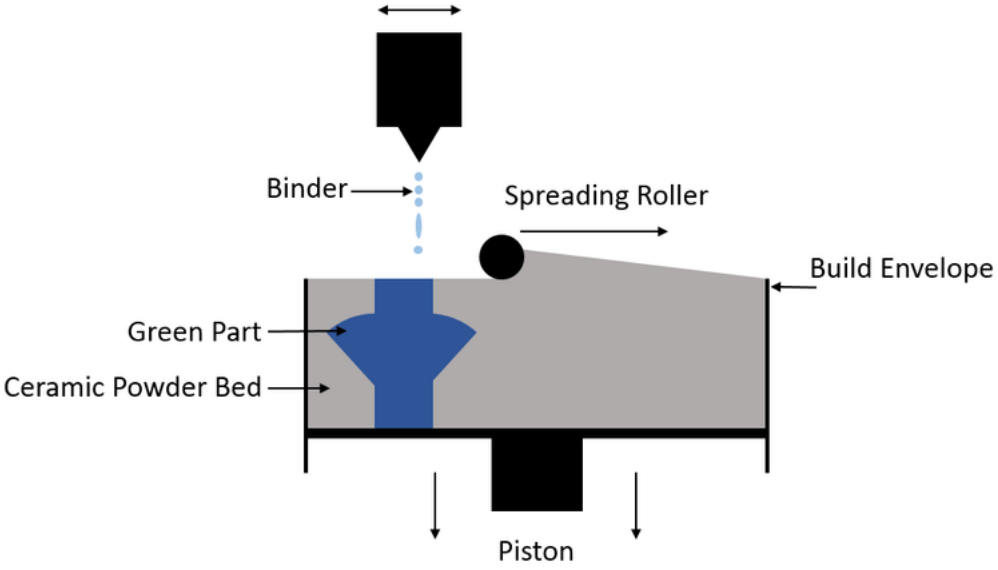


Figure 9: Schematic Illustration of the Binder jet technique.[15]

2.10.4 Comparison between the three techniques

The three main types of additive manufacturing, namely concrete printing, contour crafting, and D-shape, have some similarities. Using cement-based paste for concrete printing and cement mortar for contour sculpting, for example, all of these processes entail extrusion. Additionally, contour crafting and D-shape employ a single material, but with several techniques to produce diverse results, whereas concrete printing uses a secondary material to support overhangs. While D-shape uses unconsolidated material to offer support, contour crafting mostly creates vertical pieces that don't require further support. Last but not least, the final product is constructed using a layered process in all three types of additive manufacturing.

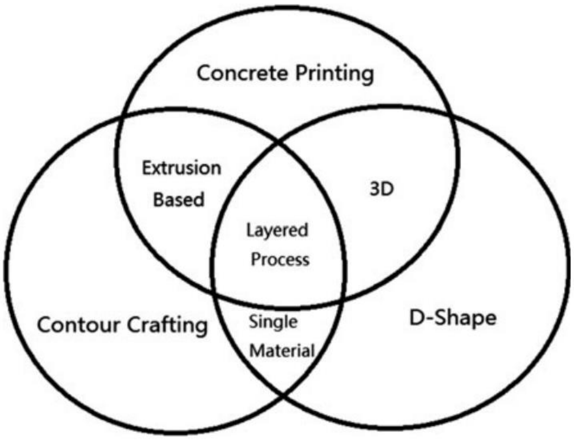


Figure 10:Similarities between the three techniques mentioned11]

2.11 Materials

2.11.1 Commonly used materials :

Currently, concrete dominates the construction industry as the primary building material utilized worldwide. This is due to the easy accessibility and availability of its main raw components. Its malleability and structural capabilities, stemming from its state before setting, also contribute to its widespread usage. However, concrete is limited to a finite number of construction techniques. Usually, it is cast into an already-existing mold that has steel reinforcements placed in it before pouring.[18] This procedure can be carried out on-site or off-site, but both locations require a significant amount of effort and experience because professional workers are needed to build the mold and put the reinforcement. Another problem is the possibility that the formwork's material may not always be reused. As an alternative, the extrusion technique can create particular building materials, like hollow-core floor slabs. However, because the extruded component is unsupported after leaving the formwork, this method heavily relies on low slump and quick-setting concrete. [18] Despite being widely used, concrete has negative effects on both people and the environment. Concrete must be produced using a lot of energy because slag must be burned in a kiln, which produces a lot of CO2 emissions. According to the World Business Council on Sustainable Development, around 5% of global CO2 emissions are attributable to the production of cement alone. [18]

Concrete building methods not only have an adverse effect on the environment, but they also seriously jeopardize the physical well-being and safety of workers. Unguarded machinery, unfavorable body positions that can cause sprains or strains, and irritation of the skin, eyes, and respiratory system brought on by exposure to cement dust are all factors that put workers at risk for injuries, according to a report by Occupational Health and Safety Administration in the US Department Of Labor.Furthermore, the costs associated with formwork and the constant pressure to reduce construction expenditures lead to the adoption of simplistic designs that do not make optimal use of materials. These factors create limitations in the development of more sustainable and innovative construction practices.[23]

2.11.2 3D Mixtures.

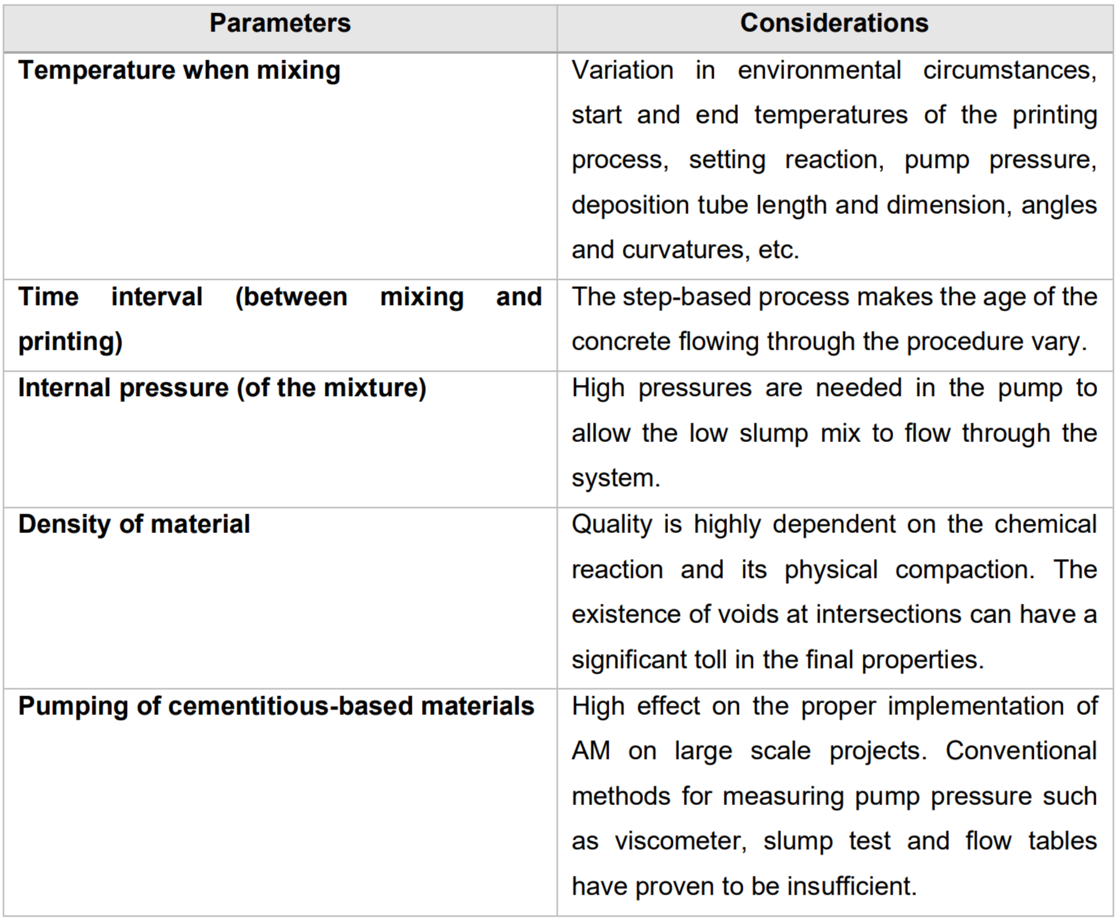
In order to improve the handling properties of the mixture, additive manufacturing (AM) technique typically combines bulk materials like crushed stone, soil, clay, and sand with a binder like cement, fly ash, or polymers and a number of additives or chemical agents.[20] Among these materials, cementitious-based mixtures appear to be the most practical option for AM in the construction industry. These combinations have special qualities in both their liquid and solidified phases, which makes it possible to adjust them with a variety of tools and admixtures to improve and personalize their performance.

However, a significant barrier to optimizing the admixtures is the absence of established procedures or pertinent techniques for assessing the quality and suitability of these mixtures. The advancement of better and more useful AM procedures in construction is still constrained in the absence of precise rules for measuring and evaluating the characteristics of these materials.[20] Materials based on cementitious materials need to set quickly and have little slump in order to be used in AM technology to avoid the extruded material collapsing from lack of support. The capacity to manage the extrusion process depends heavily on a number of factors, including viscosity (which depends on the mix design and the water to cement ratio), mass, and particle size.[20]

Extensive study is needed to establish the correlations between different parameters in order to build mixtures with certain properties, such as self-compaction, minimal carbon footprint, high strength, workability, ductility, and viscosity. The outcome of the procedure can be significantly impacted by even small changes in the mixture's ability to modify how the substance behaves when it is in a fluid state. Therefore, optimizing the mixture design is a complex process that requires careful consideration of various factors to ensure successful and efficient AM in construction.[20]

Bos and colleagues were granted access to the AM facility of Eindhoven University of Technology (TU/e), where they had the opportunity to observe the concrete printing process. Typically, a mixture of concrete and water is combined and then pumped through a mixer-pump into a hose. The hose guides the mixture to the printer head, which is located at the end of a vertical arm on a motion-controlled gantry robot. Using this machine, printing an area of 9.00 meters in length,4.5 meters in width and 2.8 meters in height meters is achievable.[24] Concrete is extruded based on pre-programmed settings that include location, speed, and angle thanks to the pressure from the pump, which pushes the material in the direction of the printer head. The rectangular shape of the printer head, which measures 40 x 10 millimeters, enhances buildability, thus requiring the nozzle's orientation to remain tangent to the path. To determine the print speed and pump frequency, a parameter sensitivity test program is conducted.

The interconnection between these three parameters (speed, frequency, and head shape) is contingent on the viscosity of the concrete mixture.



Parameters	Considerations
Temperature when mixing	Variation in environmental circumstances, start and end temperatures of the printing process, setting reaction, pump pressure, deposition tube length and dimension, angles and curvatures, etc.
Time interval (between mixing and printing)	The step-based process makes the age of the concrete flowing through the procedure vary.
Internal pressure (of the mixture)	High pressures are needed in the pump to allow the low slump mix to flow through the system.
Density of material	Quality is highly dependent on the chemical reaction and its physical compaction. The existence of voids at intersections can have a significant toll in the final properties.
Pumping of cementitious-based materials	High effect on the proper implementation of AM on large scale projects. Conventional methods for measuring pump pressure such as viscometer, slump test and flow tables have proven to be insufficient.

Table 3:The primary factors influencing concrete printing with cementitious-based materials and potential areas for developing a relationship between material and design.[17]

Accelerators can be added or the proportions of the cement and limestone fillers can be changed, as is typical in conventional mixtures, to alter the characteristics of concrete. A no-slump concrete mix makes it simple to understand how the print path, nozzle opening, and printed geometry relate to one another, which improves precision and makes it possible to stack layers on top of one another. Another essential aspect is a long setting time, which allows for sufficient chemical activity on the surfaces to facilitate bonding between layers and reduces the dependence on the time separating subsequent layer deposition.[25] Due to the experimental phase of concrete mixtures, institutions involved in AM with concrete research and implementation avoid publishing their material composition, although a fast-setting blend with a higher slump is generally required for proper system operation [26]

Sulphur concrete is also a promising material for printing building elements, as it is composed of Sulphur, coarse aggregates (e.g. gravel or crushed rocks), and sand. The mixture is heated to approximately 140 degrees Celsius, the melting point of Sulphur, and then cooled to achieve the required strength, eliminating the long curing times needed for traditional concrete [23]).

Table 4 summarizes Ghaffar et al.'s (2018) research on the use of mixtures, additives, and resulting density and strength.

Developer	Mixture	Additives	Final Strength
Loughborough University	54% sand, 36% reactive cementitious compounds, and 10% water by mass	CEM I cement, fly-ash, un-densifier silica fume, retarders, superplasticizer, accelerators, polypropylene microfibres.	Compressive – 75-102 MPa Flexural – 6-17 MPa The tensile bond strength between layers – 0.7-2 MPa
Loughborough University (Le et al.)	70% cement, 20% fly ash, 10% silica fume	Micro-polypropylene fibres	Compressive strength – 110 MPa
Jeon et al.	30% fly ash, 10% silica fume, 60% Portland cement	n/d	Compressive strength – 55 MPa
Bos et al.	Portland cement, siliceous aggregate (1 mm) limestone filler	Additives for ease of pumping, rheology modifiers and polypropylene fibres	Compressive – 30 MPa Flexural – 5 MPa
Hambach and Volkmer	61,5% Portland cement, 21% silica fume, 15% water and 2,5% water reducing agent	Carbon fibres	Compressive – 83 MPa
Khalil et al.	93% Portland cement 7% Calcium	Superplasticizers	Compressive – 79 MPa

Table 4:Applied mixtures and additives and their results.[17]

2.11.3 Polymers:

Polymer materials can be a feasible choice for additive manufacturing in construction due to their low cost, low density, and ease of storage. These materials have been used in diverse fields such as medicine, aerospace, architecture, art, and education, mainly for creating conceptual models and prototypes. [24]However, because to a lack of the needed structural and load-bearing characteristics for functional components, their practical implementation is currently limited.[20] The main cause of printed products' low mechanical capabilities is the presence of voids, and adding reinforcements to fix this problem could actually make the porosity worse. To improve bonding and obtain superior mechanical qualities, the polymer matrix and fiber compatibility must be improved. Superior mechanical qualities can arise from filaments with a high fiber content, but too much fiber might make a material challenging to print and cause nozzle blockage.[20]

Their deficiency in mechanical abilities is primarily caused by the presence of empty spaces that are typical in printed objects. Introducing reinforcements may exacerbate this problem by increasing the porosity since the connection between polymers and reinforcements is often weak. Enhancing the bonding between the polymer matrix and fibers will be critical for improving the bonding. High-fiber content filaments result in materials with distinguished mechanical qualities, although adding fibers is often restricted to about 40% of the composition because adding more causes the material to be difficult to print and prone to the paste clogging in the nozzle [20]

2.12 Alternative Sustainable Materials

Additive manufacturing technologies, combined with eco-sustainable construction methods, have the potential to revolutionize the construction industry by allowing for the efficient design and production of complex structures with reduced energy and material usage. The use of earthen composites in 3D printing can further reduce the environmental impact of construction while also improving worker safety and reducing costs. However, the successful use of earthen materials in 3D printing requires a thorough understanding of their rheological properties and the factors that affect their performance. Some studies around alternative and carbon neutral materials have been done and some promising findings were concluded.

2.12.1 Raw Earth

Raw earth has been tested as a 3d printable material in many university types of research. A study done At the University of Rennes tested the compressive and tensile strength of the of earth when combined with alginate in an attempt to make the hardening process faster, the material that was tested originated from Saint-Sulpice-La-Forêt, located in Ille et Vilaine, France, and was in its raw state. The soil tested was mixed with water, and alginate, and was printed in cylindrical shapes as well as rectangular forms. Cross sections were made and the compressive strengths of the mixtures were measured. The study includes several figures that illustrate the different techniques used in 3D printing with earth-based materials.[27] These figures demonstrate the printing process and the various factors that affect the quality and performance of printed structures.

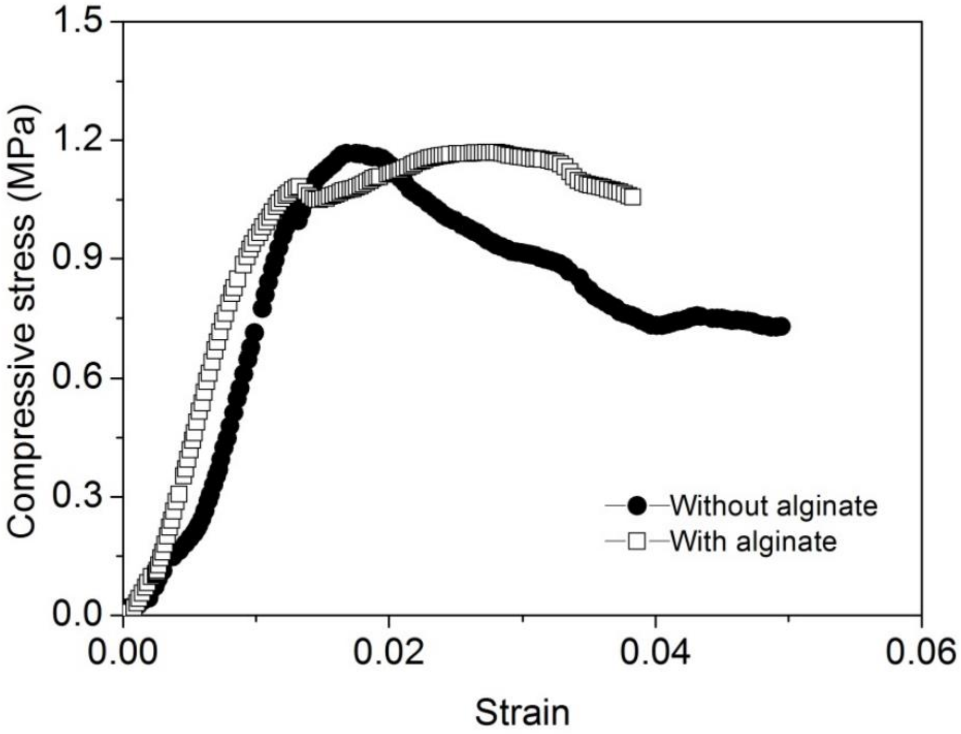


Figure 11: Compressive strenght of a circular section with and withou Alginate

Overall, the study concludes that 3D printing with earth-based materials has the potential to revolutionize the construction industry, but further research and development are needed to fully realize this potential. Another study done by students of ENSAM demonstrated that bacterial cellulose (BC)can be effectively used as a soil additive for additive manufacturing processes. The addition of BC had a positive impact on the mechanical resistance of printed samples in compression and bending and also reduced the dimensional change (shrinkage) of the samples. The addition of BC also prevented cracking even at high water contents.[27]

2.13 The Printing Process:

Previously mentioned is the difficulty in analyzing and comparing the various print processes used worldwide due to the reluctance of researchers to share the latest discoveries. This technology is used in many projects, but details such as the printed parts, materials used, and equipment operation are unknown. Most additive manufacturing (AM) machines are designed for smaller sizes, but a Chinese construction developer claims to have used a large polymer printer to produce dwellings in Suzhou, China.[20] However, no data has been published on this matter. The present systems demand expert operators, extensive planning, and careful consideration of material design. The behavior of mixtures, operational limitations, and directions supplied to the machine to manufacture the element all present difficulties. It I suggested that three main parameters need careful consideration when implementing AM for large construction components: printable feedstocks, printers, and geometry[26]. A successful process depends on the mixture's composition, the employment of various additives, and 3D printers equipped with pumps that can continuously distribute a mixture at a set rate. The size and speed of the printer can influence the edges, consistency, and surface quality of the product. Finally, achieving full-size building geometries depends on the successful fulfillment of the parameters mentioned above, with truss-like structures and self-reinforced shapes being effective in achieving the required strength and stiffness in structural elements.

The differences between conventional 3D printing and printing on concrete must be considered. Due to the exothermal hydration reaction that begins as soon as water and concrete are combined, the solidification of print material in concrete printing is a slow process. This means that the bottom layers' status is distinct from the layer that is now being printed, in contrast to the majority of non-concrete 3D print procedures where the material quickly solidifies. [19] For concrete printing to be successful, mixture properties including strength and stiffness development over time must be adjusted. Concrete has special characteristics that call for further study, including creep, shrinkage, and age-dependent strength. Additionally, the size and linear filament deposition in AM geometries of concrete printing vary.[26] The alternatives for various geometrical prospects are where concrete printing has its restrictions, and the attributes of the printed output are determined by the procedure's predetermined parameters. CAD files cannot be transferred directly for printing; instead, experts must convert the model into a format that can be printed. From a design and structural standpoint, flattening three-dimensional objects into two dimensions is not ideal since it can introduce shifts when two layers are stacked on top of each other and restrict the possible geometries. At the Rotterdam Trade Fair, a design workshop for architects showed that printing parts required extensive reprocessing by experts.[26]

2.13.1 Relationships and Dependencies.

When printing concrete elements, it is crucial to have a solid connection between the design process, the material used, the process and the products, and this connection in this case, is much more important than in the case of conventional 3d printing of products for example. This is due to the fact that printed concrete has a slow setting time and has a strong relationship with printing parameters like speed and pressure, as well as the fact that there is no standard concrete mixture recipe. Normally, self-compacting concrete or post-cast vibration are used to accomplish compaction, but neither of these methods is practical for printing concrete. This means either the mix needs to be changed or the system needs to be re-checked in order to achieve substantial compaction. It is necessary to guarantee quality homogeneity for various designs if 3D-printed concrete structures are to be used for load-bearing constructions. To determine which factors affect the final quality of printed items, it is required to upgrade additive manufacturing facilities for concrete. To enable comparisons with regularly used concrete, data on shared characteristics like creep and shrinkage must also be gathered, and strategies for joining printed pieces together must be established.[26] The key issue to be resolved is whether it is possible to develop a standard approach that can provide sufficient strength, durability, and overall robustness for structural applications using 3D concrete printing. [26]Unlike traditional concrete applications, it is difficult to incorporate steel reinforcement into 3D printing. Alternative methods have been employed, though, including post-tensioning prestress bars, sandwiching glass fiber between layers, placing reinforcements between contours, and using the printed layers as a mold rather than a structural element when casting concrete between the reinforcements. In-depth studies on fiber-reinforced printable concrete with the necessary ductility and tensile strength, such as Ultra-High-Performance Fiber Reinforced Concrete (UHPFRC), have revealed that it performs well under different load settings in terms of compression and tensile strength, firmness, fracture energy, and crack opening. [19] Additionally, concrete has been combined with different fibers like glass, basalt, or carbon fibers, producing effective structural results.

2.14 Requirements and Challenges

The concrete printing process depends on many factors and prerequisites to be successful. A lot of these factors concern the concrete mixture used and the state of the concrete that is being printed. These factors are measured with pre-defined benchmarks to attain the desired mixture components. These challenges can be divided into three main aspects: The 3DCP. Fresh State Challenges, Hard State Challenges, and Geometric Conformity.

2.14.1 Fresh State:

In the construction industry, it's critical that the additive manufacturing (AM) process complies with design criteria and has toughened qualities. Understanding the qualities and traits of the wet mixed mortars which are utilized for printing is essential for the effective implementation of AM in the construction industry. To be pumped via a nozzle and maintain their shape with little to no deformation, these mortars need to have characteristics.[21]

Pumpability, buildability, and extrudability were the three qualitative descriptors that were defined for the AM process in the construction industry.[28] To comprehend the interaction between design and printing, a study has been done on the science of deformation, and on the physical properties of mixtures. An important aspect of additive manufacturing (AM) is the material's "open time," or the period of time during which it is useful and workable on a 3D printer. Another crucial element is the setting and layer cycle time, which refers to the time required to finish one layer and its effects on subsequent vertical coats. Rheology examination and material deformation when additional layers are extruded both significantly affect quality debates.[19]

2.14.2 Open Time

The term "pumpability" refers to the quality that indicates how easily a mixture can be transferred from a pump to an extrusion nozzle. Due to how sensitive the process is to interruptions, it can be detrimental when obstructions in the hose arise from mix design or procedural problems. This is because in order to achieve a uniform product, sequential layers must bond together. [29]Cold joints between layers are more likely to form with longer open durations. This issue has frequently been solved with positive displacement pumps and mixes with enough paste content to generate a lubricating layer inside the pipe. Open time is an important factor to consider when using 3D printing technology in construction because the printing process can be time-consuming, and the material should remain workable throughout the process. The open time is affected by the composition of the mixture, the environmental conditions, and the printing parameters[19]. If the material sets too quickly, it can cause clogging of the printing nozzle or lead to an incomplete print. On the other hand, if the material remains too fluid for too long, it can cause deformation or collapse of the printed structure. Therefore, it is important to carefully select and test the mixture to determine its optimal opening time for the printing process.

2.14.3 Layer Cycle-time:

To make a printed component, the extrusion must adhere to a predetermined path to deposit material, which is then repeated to build up the vertical height layer by layer. Critical elements influencing production time and interlayer bond strength are the length of the extrusion path and the speed of material placement.. Rectangular nozzles have reported speeds of 30mm/s to 35mm/s, while circular nozzles have speeds ranging from 50mm/s to 66mm/s. However, the rate of material deposition during a change in direction is a limiting factor in print speed. The fundamental structure of the process prevents the tool path from ever being linear, and a number of factors, including the inertia of the extruded material, restrictions on the position equipment, cycle times between layers, and geometrical flaws during layer deposition, restrict the rate of deposition. The manufacturing process, material qualities, process characteristics, and the size, shape, and hardness features of the component being produced all influence the tool path design. [19]

2.14.4 Self-Deformation

To ensure adhesion to the prior layer, the filament is carefully deformed during the deposition process in 3D printing. Low yield stress is necessary for pumping, but once the printed filament is in situ, it must keep its shape. The form of the filament and layer adhesion might change as a result of variations in layer height caused by yield stress. [19]The layers contract under their own weight as the build height rises and the hydrostatic pressure rises. In order to maintain a constant layer height, the distance between the nozzle and the surface where the work is happening, must be increased, which could affect layer adhesion and cause the filament to buckle and collapse. Early-age mechanical behavior and modeling are crucial factors to take into account because this issue is particularly severe in tall structures that are built vertically. Two techniques for tackling this problem include dynamic nozzle height adjustment during printing and careful building rate management, which may require injecting accelerators prior to extrusion to speed up the hardening of lower layers. To avoid strength-based failure during the printing process, Roussel presents a set of specifications for printable concrete.[29]

Hard State:

In fact, AM mixes can achieve higher material densities than their cast-contemporary equivalents, and they have proven to be structurally similar to traditional concrete cast elements. The technology is not yet advanced enough to guarantee "as-good-as" attributes on a broad basis, though. Anisotropy is produced when layers are extruded, which can have an effect on how well the final product performs. Relevant study areas may include understanding how these fundamental process characteristics behave and how to minimize their detrimental impacts.[19]

2.14.5 Adhesion of Layers

The potential for cold joints to form between extruded filaments is the key concern with regard to layer adhesion. In this situation, the deposition cycle time is excessive, but other factors, including sand particle size, may also be detrimental. For the process to be successful, especially later during the process, where hydrostatic pressure increases due to adding layers, the extruded material must adhere to the prior layer and keep its shape. The four types of adhesion that are possible are temporary weakly bonded, weakly bonded, weakly bonded as a result of shrinkage or carbonation, and weakly bonded overall.[19]

The geometry of the component that needs to be printed has a significant impact on the times between layer extrusions, as was already mentioned. Understanding how the entirety of the printing process might inluence the layer cycle-time and eventually the strength of the 64 pieces will be crucial, especially when it comes to the design of structural modules. [19]

2.14.6 Under-filling and bulkiness

Results for some geometry must have "as good as cast" density characteristics. Under-filled mixtures may result in voids between the filaments, lowering the hardened material's effective density and impairing the component's durability. A suitable mix design and stable rheological qualities must be obtained in order to reduce voids. The chosen admixture's ability to deform is crucial because without it, material cannot be pushed into potential voids to fill them[19]

Changes in direction could promote the growth of voids. There is a maximum radius that the filament can follow, which is frequently specified by the design of the material and the geometry of the nozzle, therefore variations in the course have an impact. The wet characteristics of the mixture, nozzle size and shape, and printing speed all affect this radius's quality. [19]

2.14.7 Tensile reinforcement

If additive manufacturing (AM) is ever to progress beyond the production of prototypes and aesthetically pleasing elements and in fact become capable of playing a mor important rolel for the construction industry, the ability to incorporate tensile reinforcement into the AM process will be a crucial component. Steel or other types of reinforcement must be utilized since cementitious mortars have a constrained tensile capacity. Textiles can provide this support for such a way of installing reinforcement parallel to the printed

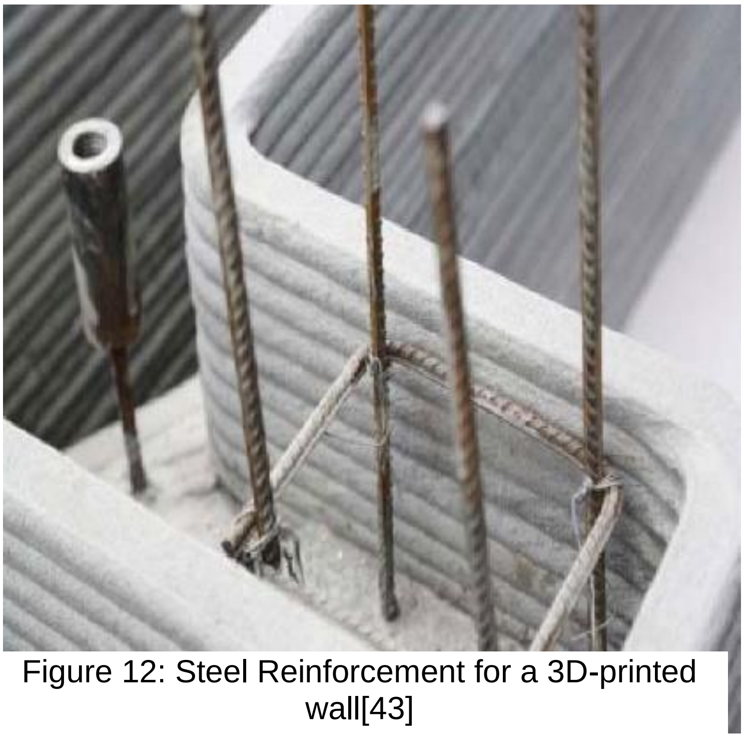


Figure 12: Steel Reinforcement for a 3D-printed wall[43]

layers, but it could not be sufficient in some cases where steel rebar might be necessary. If that is the case,the layer thickness and extrusion diameter will depend on the diameter of the rebar in the latter scenario. In some situations, it can be necessary to add reinforcement parallel to the extrusion layers.[19]

Conventional techniques involve printing extruded layers over typical steel reinforcement structures, which will then be cast with concrete. This offers a significant benefit because structural capabilities may be taken into account using the current codes [19] Regarding this topic, more study is needed. This is particularly relevant when discussing issues like how printed reinforcement encasements ultimately affect reinforcement tolerances and how reinforcement can be applied to increasingly complex geometries. [30]The second is particularly important because giving architects and designers more design flexibility is one of the most fundamental advantages of AM in construction. Figure 14 displays images demonstrating the use of 3D printed concrete as formwork for vertical, load-bearing components.

2.14.8 Shrinkage and toughness

There are undoubtedly benefits to removing formwork during the construction process, particularly in terms of cost and trash. [29]However, doing so exposes the curing concrete to the contaminant of the surroundings in a positive way. Because printed components frequently have a larger surface area exposed to the environment and because printing mixes typically have low water/cement ratios, the likelihood of cracking is increased throughout the entire process. Because of this, shrinkage-related dimension changes in admixtures must be kept to a minimum while curing is handled with greater care. [19]

2.14.9 Hardened characteristics measurement

Due to the anisotropy of 3D printed concrete buildings, Buswell et al. (2018) propose that there are many fresh potentials for more research. Samples are cored or sawed in order to analyse and comprehend the hardened characteristics of printed parts. While some experiments expressly set up the process for evaluation, other tests have been run under "typical printing conditions." The main issue is that there is no reliable way to display information about the printing process, such as the nozzle size, filament dimensions, print rate, layer height, component size, and deposition cycle timings. In other words, no tested methods exist that produce a reasonable range of comparable results. [19]

2.15 AM in construction: Socio and environmental impacts

Raw financial success has become less significant in society as a whole in favour of adjusting not only for the socio-economic need but also for the environmental needs of the modern world. AM technology must take into account these specifications and chosen with the understanding that they can undoubtedly offer creative and sustainable environmental solutions. Effective waste processing and building demolition activities will be required to accomplish this and maybe support a future circular economy model in the construction industry. Additionally, appropriate materials must be created. The foundation of AM will need to include the development of an economically viable process that is focused on meeting user needs with the least amount of waste and toxic ingredients. But it will be crucial to comprehend sustainability throughout the building's lifespan, not just with regard to its effects on the environment during the production phase.[15]
As a result of its ability to improve resource efficiency, AM can significantly lessen the process's negative environmental effects. Additionally, it might encourage potential sustainable production and consumption models.[20] If the material is not required, it can be recovered, which might lead to on-site recycling systems that can send the materials back into waste-resource streams that create new raw materials. The technology might lower production costs by €155–540 billion

(109), the total energy supply by 2.54–9.30 exajoules (EJ) (1018), and carbon dioxide emissions by 130.5–524.5 metric tons (Mt) by 2025.[20[20]

2.16 Safety

Construction sites distinguish themselves as being frequently chaotic settings full of a variety of people, trades, and possible risks.

Robots can replace human workers, which can improve productivity, quality, and safety. The use of automation technology for some activities is becoming an increasingly more appealing notion due to the increase in labour prices and the scarcity of skilled labour.[15]

Currently, automation equipment is mainly used for dangerous and taxing work.

For instance, since it is a repetitive task, robots can readily perform bricklaying and roadway paving. This may lessen the workloads of bricklayers, which can be quite heavy and result in accidents. When bricks are loaded and unloaded into a wheelbarrow, the most tension is experienced. As a result, some businesses have created brick laying robots with a variety of features. The way such technologies are presented depends on how the developer or inventor feels about the potential for robot use.[15]

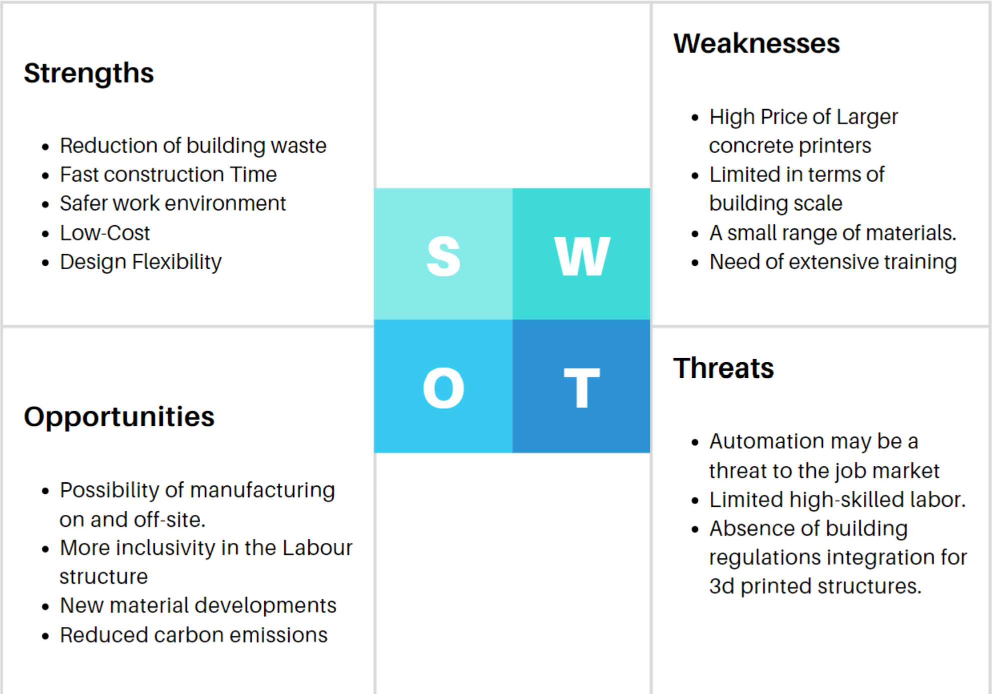
These instances lead one to the conclusion that robots have gradually left the laboratories and are now playing a more active role. These might potentially solve a lot of the issues that typically plague on-site construction.

Additionally, it might provide architects with the ability to create whichever they like without being constrained by conventional building processes.

Their adoption, however, can only take place gradually because it goes against conventional construction techniques and approaches and still has a lot to prove.[15]However, there is skepticism about the use of this technology to some extent. Some expect that present employment positions will be replaced by new ones that are better qualified, while it is widely thought that automation will eventually result in the loss of jobs. People could engage in more creative activities as a result of this. In addition, as previously noted, the use of such equipment would encourage women to participate in the sector and will enhance the health and safety conditions of laborers engaged in construction activities by lowering accidents and increasing their time on the job.[15]

2.17 Additive Manufacturing in the Construction Industry- Strengths, Weaknesses, Opportunities and Threats.

There are several reasons to include AM in the construction industry in addition to the benefits already mentioned. When done properly, including mechanical and electrical systems within the spaces made possible by a structure's printing can help to maximize the usage of materials. Another argument is that integrating procedures might lessen the need for corrective actions, which are frequently costly and time-consuming. Third, new finishes can be created by better managing the use of the building materials. Last but not least, the application of AM can give architects more design freedom [15]



Strengths

- Reduction of building waste
- Fast construction Time
- Safer work environment
- Low-Cost
- Design Flexibility

Weaknesses

- High Price of Larger concrete printers
- Limited in terms of building scale
- A small range of materials.
- Need of extensive training

Opportunities

- Possibility of manufacturing on and off-site.
- More inclusivity in the Labour structure
- New material developments
- Reduced carbon emissions

Threats

- Automation may be a threat to the job market
- Limited high-skilled labor.
- Absence of building regulations integration for 3d printed structures.

Table 5: SWOT analysis for AM in the construction industry

3 Methodology.

3.1 Literature review points made:

From the literature review made in the previous chapters, It is evident that additive manufacturing has solid potential in terms of Efficiency in construction. An argument that 3d printing is more efficient than traditional construction methods in terms of Cost of materials, Labor, Time, waste, and carbon emissions can be made. All these factors are crucial when the project involves emergency shelters. After a disaster, governments and other organizations that are involved in relief efforts, need to be fast and efficient in order to save lives and provide safe spaces to people affected. Hypothetically, the ability of 3D printers to create structures quickly and efficiently, meeting the immediate demand for shelter in disaster situations, is one of their main advantages. Furthermore, 3D printing is economical, lowering building costs by maximizing material consumption and lowering labor costs. Additionally, flexibility and customization are made possible, enabling the design of specialized shelters to suit certain requirements and environmental factors. The use of locally accessible materials in 3D printing encourages resource conservation and sustainability. The resulting shelters may have sturdy construction and be built to last for a long time.

3.2 Research Questions to be proven:

In order to prove these points, a deductive case study method was done on a shelter design suitable for 3-4 people. Time and cost analysis will be made, and results will be considered. Two other case studies will also be considered in the following section in order to provide a comparison space on the process of building shelter camps and the average cost and time needed to complete these projects. Thes case studies have been picked specifically to answer questions such as:

-Is 3d printing a solution for emergency shelters and disaster housing?
-How does 3d printed shelters compare to traditional shelters in terms of Cost of material, labor, time and waste?
-Can shelters be printed from materials other than concrete?

The answers will be concluded from the following Studies.

3.3 Case Studies:3D printing cases:

In this section, The Case studies selected aim to provide live examples of cases where 3DCP provided solutions and innovation which could be used in the research. The first case study depicts a shelter made completely of soil, which is a material found on the site for virtually Zero cost. This can be groundbreaking in terms of cost reduction and sustainability. The research will go into detail on the

Figure 13: TECLA printed structures (Copyright © Mario Cucinella Architects and WASP, 2021). Photo by Iago Corazza..

technicalities of this project and conclude main points that are relevant to the subject at hand.

3.3.1 1:Round Houses of Raw Earth: 3D Printing Sustainable Homes in 200 Hours

The premier 3D printing company in Italy, Wasp, and Mario Cucinella Architects have built the first house that was 3D printed from unfinished earth. The Tecla (technology and clay) method is eco-sustainable and environmentally friendly because no trash is generated during production, and no materials need to be transported to the site because it uses local soil. The house's organic, cave-like appearance gives the impression that it was chiselled out of nature thousands of years ago, visually contradicting the cutting-edge technology it uses. It is characteristic of Cucinella's work, which focuses on "humane" architecture and blurs the lines between low-tech and high-tech. Massimo Moretti, the founder of Cucinella and Wasp, conducted research at the School of Sustainability on the need for sustainable dwellings at Km0, i.e., using materials found on site to mitigate the environmental effects of shipping materials to building sites. This research served as the foundation for the project. Tecla, an essentially emission-free and low carbon process, is the result. Moretti continues, "Tecla demonstrates that a beautiful, healthy, and sustainable home can be produced by a machine.[31]

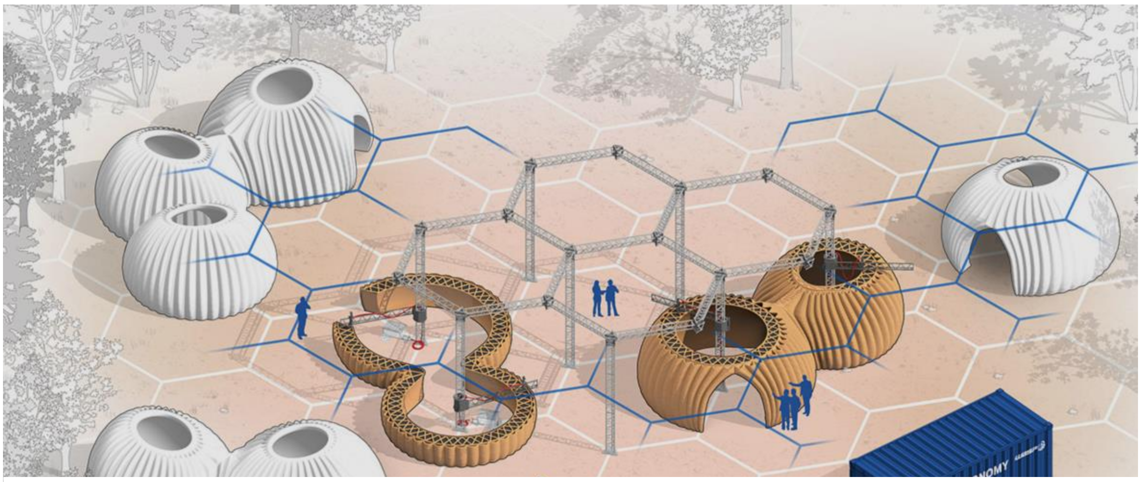


Figure 14:Tecla house modules (Copyright © Mario Cucinella Architects and WASP, 2021). Photo by Iago Corazza.

The architect researched how a building's design, in relation to its temperature and latitude, could affect its efficiency. He also looked at how the material makeup of the building could aid in insulation and ventilation. The house's structural equilibrium is also made possible by its shape and outside ridges. A living room, kitchen, and bedroom are all inside. Some furniture is built into the building, while other pieces are free-standing and made to be recycled or used again. The structure uses 60 cubic meters of natural materials and 350 12mm layers, with an average energy consumption of under 6kW.[31]

Figure 15:Tecla house raw earth printing (Copyright © Mario Cucinella Architects and WASP, 2021). Photo by Iago Corazza.

Designed by MC A, and manufactured by WASP .WASP(World's Advanced Saving Project) has been working to develop workable construction methods based on the concepts of the circular economy that will produce 3D printed homes in the shortest amount of time and in the most sustainable way feasible since 2012, drawing inspiration from potter wasps.[32]

An additional hurdle to the project was using raw earth as the primary material. The double dome shape of the project, which includes the structure, roof, and wall cladding, is its most visually appealing feature. This will allow the speed up construction, uses fewer resources, and simplifies the building process.[32]

TECLA will be the first habitat to be constructed utilizing numerous cooperative 3D printers, providing a larger scale than previously. TECLA has the ability to serve as the foundation for entirely new autonomous eco-cities that are off the present grid when used as part of a larger design.[32]

In relation to that, the basic kit for building these spherical buildings comes with various 3D printers and a method for mixing the ingredients. Through the use of 7000 machine codes and 60 cubic meters of natural materials, one TECLA could be manufactured in 200 hours. [31]Each printing unit has a printing area of 50 square meters, according to the developers, making it possible to construct autonomous dwelling modules in a matter of days. This habitat prototype may serve as an inspiration for future efforts to build effective and long-lasting habitations. In addition, they anticipate that the TECLA will be environmentally responsible while addressing the ongoing problem of rising populations and a scarcity of affordable housing. It might serve as the foundation for brand-new off-grid, eco-friendly spherical dwellings. This design is even more unique because it is biodegradable, which means that when some of the spherical houses are no longer needed, they will decompose naturally.

Figure 16:Tecla house interior (Copyright © Mario Cucinella Architects and WASP, 2021). Photo by Iago Corazza.

Key Findings:

1. Sustainability: Throughout the course of its development, TECLA demonstrated a high degree of sustainability. The project reduced the environmental impact associated with conventional construction techniques by employing locally produced raw earth resources combined with a little amount of water and a natural glue. Its sustainable profile was boosted by the use of natural materials and the lack of waste production during construction.

2. Circular Economy: TECLA showcased the advantages of a circular economy strategy in the building industry. The home was 3D printed using a mix of recyclable and reusable natural materials, making it simple to disassemble the printed structure and reuse the resources in other projects. This strategy encourages resource reuse and reduces waste.

3. 3. Energy Efficiency: Energy efficiency was given top priority during TECLA's design. The building's curved design enabled optimal natural ventilation and thermal insulation. Energy savings resulted from the use of native clay materials to regulate internal temperature and lessen the need for extra heating or cooling equipment.

4. 4. Design Flexibility: TECLA was able to achieve a great degree of design flexibility because to 3D printing technology. The additive manufacturing technology allowed for the house's curving shape, which was modeled after traditional earthen construction. The incorporation of organic shapes and effective utilization of space were made possible by this design strategy.

5. 5. Construction Time and Cost: TECLA showed that 3D printing technology has the potential to enable quick and affordable construction. Comparing additive manufacturing to conventional methods, building time was dramatically lowered. Additionally, the use of inexpensive, locally available materials, the abolition of formwork, and waste generation reduction reduced building expenses.

6. Scalability and Adaptability: The TECLA project highlighted the scalability and adaptability of 3D-printed construction. The technology can be easily transported to different locations, making it suitable for disaster-stricken areas or remote regions. The design and construction process can be customized to meet specific needs, allowing for adaptation to diverse contexts.

Overall, TECLA demonstrated the potential of 3D printing technology in sustainable construction, offering energy-efficient designs, reduced construction time and costs, and a circular approach to resource management. These findings contribute to the advancement of sustainable architecture and the exploration of innovative solutions for the housing challenges of the future.

3.3.2 Case Study 2: Community houses in Tabasco, Mexico

The coalition of three groups that is the subject of the second case study in this research is working together to provide access to high-quality homes along Mexico's southern border. The organization behind the agreement, New Story Charity, also provided funding for 2,300 additional low-income housing units in Bolivia, Haiti, El Salvador, and Mexico (New Story(a), n.d.). (ICON(a), n.d.); ICON, a corporation based in the United States that bills itself as a "advanced construction technologies company using 3D printing robotics, software, and advanced materials to shift the paradigm of home building for all of humanity"",[33] and Echale, a Mexican nonprofit that promotes the construction of housing and infrastructure for underserved communities. Both non governmental organizations have experience using conventional construction methods to provide social housing on a national and worldwide scale constructing specifically using cast concrete and concrete blocks. However, the collaboration with ICON made it possible for them to research 3D printing techniques for this

Figure 17:3d Printed social housing provided by ICON, in Etchale, Mexico.

particular project. The constructed homes offered by both organizations are depicted in Figure 15.

The partnership decided that their primary objective for this project was to use 3D printing to construct 50 residences in total. According to the organization, conventional construction methods face a lot of problems in being slow, producing a lot of waste as well as having poor thermal properties, and decrease comfort" (New Story(b), n.d.). They might potentially be replaced by AM technologies. Additionally, they think that their use can bring about the following advantages:

Reduced construction times; Less strenuous manual labor; Concrete's suitability, accessibility, resistance, and energy efficiency; Greater design freedom, decreased construction waste, and increased energy efficiency are all benefits of the concrete printing process. reduced from several to one the number of construction systems. (New Story(b), n.d.).

The site was agreed upon, according to the same charity, based on a number of social and technical aspects. The location was ideal for the former due to it being within close distance to the United States, the nationalities of the teams involved, local government backing for the initiative, and the ability to access the land. The latter is largely concerned with providing the industry's many poor families with access to high-quality housing. Through a collaboration with the local government, they were able to analyze 500 households and determine which ones required further assistance. The typical monthly income for the 50 households qualified for a 3D-printed home is €65.00 (New Story(c), n.d.). Due to the vicinity of the river Usumacinta and the likelihood of earthquakes in the area, communities there are also susceptible to floods. The following criteria were used to determine which families qualified:

- Identification of individuals in higher need with the assistance of other nonprofit and governmental organizations.

- Individual surveys are conducted with each family to better understand their unique circumstances.

- According to New Story(c), n.d., families are chosen based on their "greatest physical and financial need for a home."

Finance for housing comes with no interest and no profit margin. Families have seven years to pay for the construction with monthly payments of roughly €15; any remaining costs are regarded as a subsidy from New Story. These mortgage payments are put in a community fund that the families may later access rather than being administered by either of the non-profit organizations. They are to make democratic decisions over how to use these funds. Local people are also employed to clear the land, lay the foundations, and install windows, doors, and roofs in order to prevent distorting the labor market in the sector (New Story(c), n.d.). Figures 19 and 20 display the current state of the homes held by local households.

Figure 18:Existing homes conditions, photo by Joe Gonzalez (New Story)

Figure 19:Existing homes conditions, photo by Joe Gonzalez (New Story)

Lean participatory design, a lean manufacturing technique that seeks stakeholder input to improve quality, increase productivity, and improve safety, was used to carry out the design development.[34]. Families were given the opportunity to comment on the residential plan during this process, allowing for changes to better suit their requirements. Families have one last chance to decide whether or not to accept the house. According to New Story, each household is responsible for wear and tear; maintenance requirements are the same as those for a conventional concrete block home. The design development process used a lean production tool known as lean participatory design, which seeks stakeholder input to improve quality, boost productivity, and promote safety this process, housing plans might be improved and better tailored to the needs and preferences of the families who were using them.[34] The family were left to decide whether or not to take the house. According to New Story, each household is responsible for maintaining wear and tear; the maintenance required is the same as that for a typical concrete block home.

The building's prototype was completed in Austin, Texas, where ICON unveiled it during the 2018 Southwest festival. It is simple to find news and information about the event online. This model home attracted a lot of attention and gained extensive media coverage. A bedroom, combine with a living room and a bathroom, and porch were all included in the building's approximate 61 m2 (75 m2 maximum printable space). Portland cement was reportedly the primary component (2). The Fuseproject design studio of Yves Behar was given the task of creating the final design for the homes in Tabasco (Marchese, 2019). The building's architectural plans are shown in Figure 36. They include a floor plan, a front elevation, and a section A.[35]

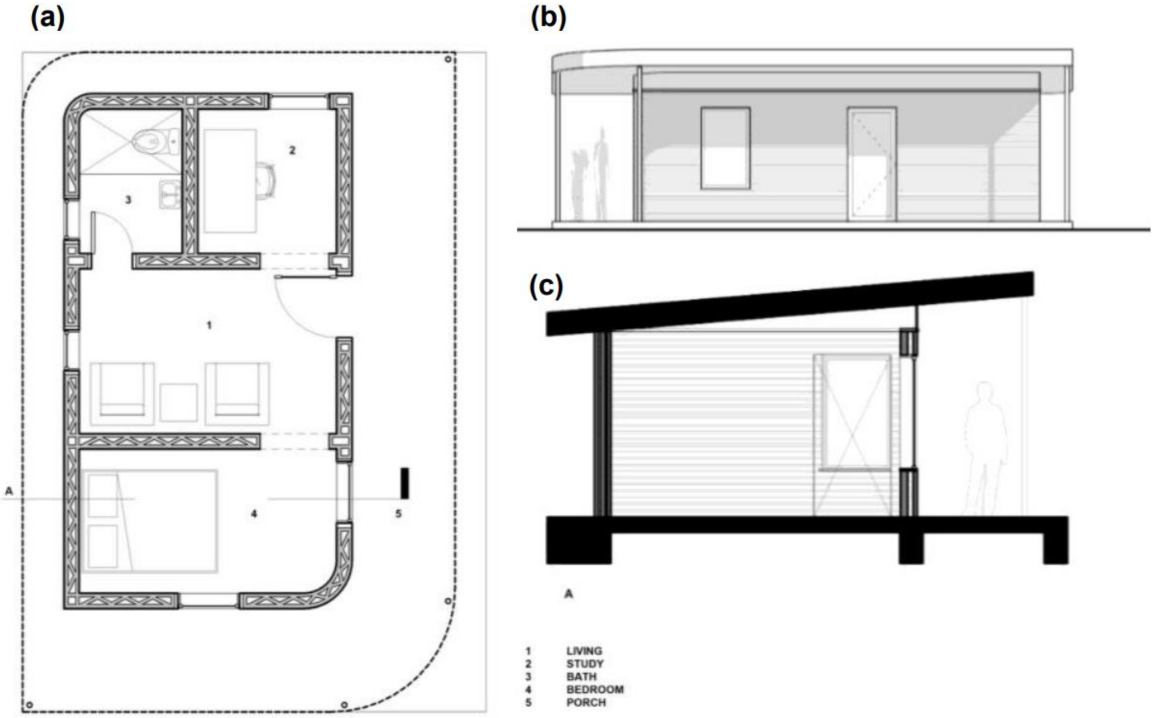


Figure 20:Plan,Section and Front Elevation of the printed houses[23]

Since then, ICON has provided updates on the technology that will eventually be fully implemented on Mexican land. The Vulcan II is a combined piece of equipment that includes the printing gantry robot system, the software that manages and supervises it, as well as the materials being used. The company claims that it is currently capable of printing 185 m2 single-story structures at a linear horizontal pace of 13–18 cm/sec. A unique program that oversees installation, use, and maintenance is connected to the tablet-based operation controls. A wall that is 2.60 meters height and 8.54 meters wide may be printed using a printer that is 3.50 meters tall by 10.05 meters wide[33]. A 220/240V single-phase connection is needed for the 16kW nominal power (35kW peak power). It can only handle ICON's "Lavacrete," a specific blend created just for their usage. This blend is ready to print and is modified for the altitude, environment, and required printing speed of the situation using a pump. Due to owner restrictions, the precise material composition of Lavacrete is not disclosed. Finally, a team of three to four people can control the robot. n.d. (ICON(b)) A photograph of the 3D printer created by ICON and used to build the first homes in Tabasco, Mexico, is shown in Figure 19.

Figure 21:Vulcan 3d printer by ICON.[33]

The project wasn't launched until after overcoming several challenges. First, the machine was kept for three months at the Mexican border. This was because such technology was novel in nature, making it challenging for officials to categorize in accordance with established standards. The rainy season had already started when the printer was given permission to enter Mexican territory, which meant that the site remained unreachable for a while owing to floods [35]These unexpected occurrences have a special connection to the in-situ launching of this project. While other structures have been successfully printed in several locations throughout the world, they have only done so under very controlled conditions. Divided over several days in order to prevent nighttime work, local craftsmen were engaged for the installation of the windows, doors, and roof; electrical and plumbing supplies are also available. Along with individual homes, the plan calls for the growth of a bigger community with the assistance of the local government. Families residing in the neighborhood are expected to have access to nearby parks, essential services, common amenities, and recreational areas (Marchese, 2019). Pictures of the finished and furnished homes that will be used to house 50 Mexican families can be found in Figures 20 and 21..

Figure 22:The 3d printed unit in Tabasco by ICON[35]

Figure 23:Interior of the 3d printed homes[36]

The completion of the community may be anticipated sometime in 2020, according to information outlets and the partnership participating in the announcement in 2019. However, follow-up by the same channels has not occurred, or at least has not been reported. both partners provide a current snapshot of the neighborhood, despite the fact that the photos below show ongoing work. Another thing to note is that El Salvador had a similar community declared before, with similar objectives and a similar overall strategy (see CNN O'Brien (2018) and CNBC, Petrova (2018)). No other information was discovered that would clarify its status besides the proclamation of such. Early in 2020, a contact attempt was made with New Story using the contact form on their website to learn more about their projects, but no response was obtained.

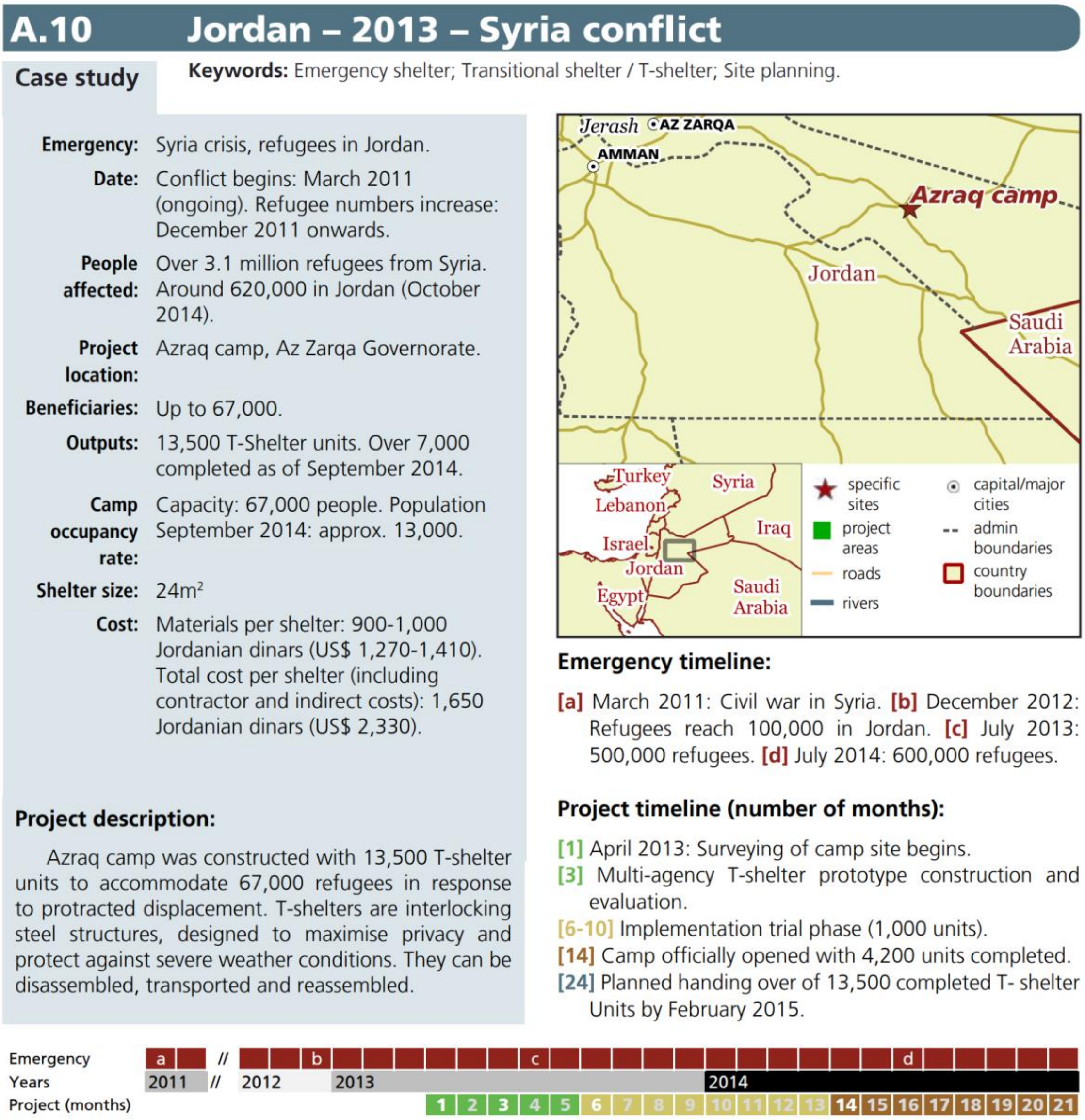
Key Findings:

Before it can even completely deploy its efforts for housing provision, A lot of obstacles occurred that made the process difficult for the world’s first 3D printed community. As with most revolutionary technology and approaches, the test has shown that it is very difficult. This is particularly relevant in light of the fact that this project was one of those that was transferred from a laboratory setting to a situation with greater practical application. Additionally, by producing a standstill at the US-Mexico border owing to costume verifications, it shows how bureaucracy can occasionally function more as a barrier than a tool for people who wish to achieve a given aim. The test has shown to be very challenging, as is expected with breakthrough technology and processes. This is particularly true when you take into account that this is one of the projects that was moved out of the laboratory and into a more on-site application situation. A further example of how bureaucracy may occasionally act more as a barrier than a help for those attempting to accomplish a certain goal is the closure of the US-Mexico border due to costume verifications. Aside from technical considerations, the project's development offers a useful illustration of how stakeholders might be considered throughout the early stages of project creation. The ultimate users' demands and requirements will be taken into account in the finished product thanks to the lean participatory design processes. This guarantees that homes are built to meet the needs of the end user rather than just what a technician, politician, architect, or engineer deems to be appropriate or in accordance with the norm. This gives individuals the freedom to choose the product they will buy and ensures that it will be one they can sustain, as was discussed in the study's opening chapters. Whether or not 3D printing technology is used in the creation of social housing, such a strategy should be taken into account in any endeavor of a similar nature.

3.4 Case Study, Conventional shelters:

In this section, case studies related directly to live shelter cases will be presented, including stakeholders, costs, projects timeline and general information about difficulties faced on one hand, and benefits gained on the other hand using these types of shelters. Key findings will also be concluded for each case in order to then compare it to the researcher own case study.

3.4.1 Azraq Camp T-shelters in Jordan 2013.



A.10 **Jordan – 2013 – Syria conflict**

Case study

Keywords: Emergency shelter; Transitional shelter / T-shelter; Site planning.

Emergency:	Syria crisis, refugees in Jordan.
Date:	Conflict begins: March 2011 (ongoing). Refugee numbers increase: December 2011 onwards.
People affected:	Over 3.1 million refugees from Syria. Around 620,000 in Jordan (October 2014).
Project location:	Azraq camp, Az Zarqa Governorate.
Beneficiaries:	Up to 67,000.
Outputs:	13,500 T-Shelter units. Over 7,000 completed as of September 2014.
Camp occupancy rate:	Capacity: 67,000 people. Population September 2014: approx. 13,000.
Shelter size:	24m^2
Cost:	Materials per shelter: 900-1,000 Jordanian dinars (US$ 1,270-1,410). Total cost per shelter (including contractor and indirect costs): 1,650 Jordanian dinars (US$ 2,330).

Emergency timeline:

[a] March 2011: Civil war in Syria. **[b]** December 2012: Refugees reach 100,000 in Jordan. **[c]** July 2013: 500,000 refugees. **[d]** July 2014: 600,000 refugees.

Project description:

Azraq camp was constructed with 13,500 T-shelter units to accommodate 67,000 refugees in response to protracted displacement. T-shelters are interlocking steel structures, designed to maximise privacy and protect against severe weather conditions. They can be disassembled, transported and reassembled.

Project timeline (number of months):

[1] April 2013: Surveying of camp site begins.
[3] Multi-agency T-shelter prototype construction and evaluation.
[6-10] Implementation trial phase (1,000 units).
[14] Camp officially opened with 4,200 units completed.
[24] Planned handing over of 13,500 completed T- shelter Units by February 2015.

Figure 24:T-shelters being erected in the Azraq Camp, Jordan 2013.[23]

The Azraq camp in Jordan was established after the protracted migration of refugees caused by the war in Syria, beginning in March 2011. As of October 2014, around 620,000 of the 3.1 million refugees that were displaced, reside in Jordan. [37]The camp is located in Az Zarqa Governorate and has a capacity of accommodating 67,000 people in 13,500 T-Shelter units. As of September 2014, over 7,000 of these units had been completed. The T-Shelter units are designed using steel structures that interlock to provide some extent of privacy as well as protection against weather conditions. These units are also easily disassembled, transported, and reassembled. The shelter size is 24m2, and the cost of materials per unit is approximately 1,000 Jordanian dinars which is equal to 1,410 US$, with the total cost per unit, including contractor and indirect costs, estimated at 1,650 Jordanian dinars (US$ 2,330). The camp's population as of September 2014 was approximately 13,000, which is a fraction of the camp's total capacity.[37]

3.4.2 Strengths and Weaknesses.

The project had it’s strengths and weaknesses. For example. The T-shelters were easy to produce and less technically complex than previous solutions, including prefabricated plywood houses, which allowed faster and cheaper production from multiple contractors.[37] They could also be dismantled and re-used, potentially forming part of a return package. On the other hand, while production was relatively fast, tents were still necessary for responding to population spikes until demand was met. One of the roofing materials, Inverted Box Rib (IBR) corrugated sheet, had to be painted white to reduce heat gain and additionally was challenging to protect against wind, rain and dust. Despite its weaknesses, the T-shelter solution was accepted, and it had a positive impact on the local labor market, with over 400 laborer employed by contractors.[37]
Other weaknesses are that these shelters have a life span of 4 years, which indicates a low degree of sustainability and high degree of waste.

3.4.3 Timeline

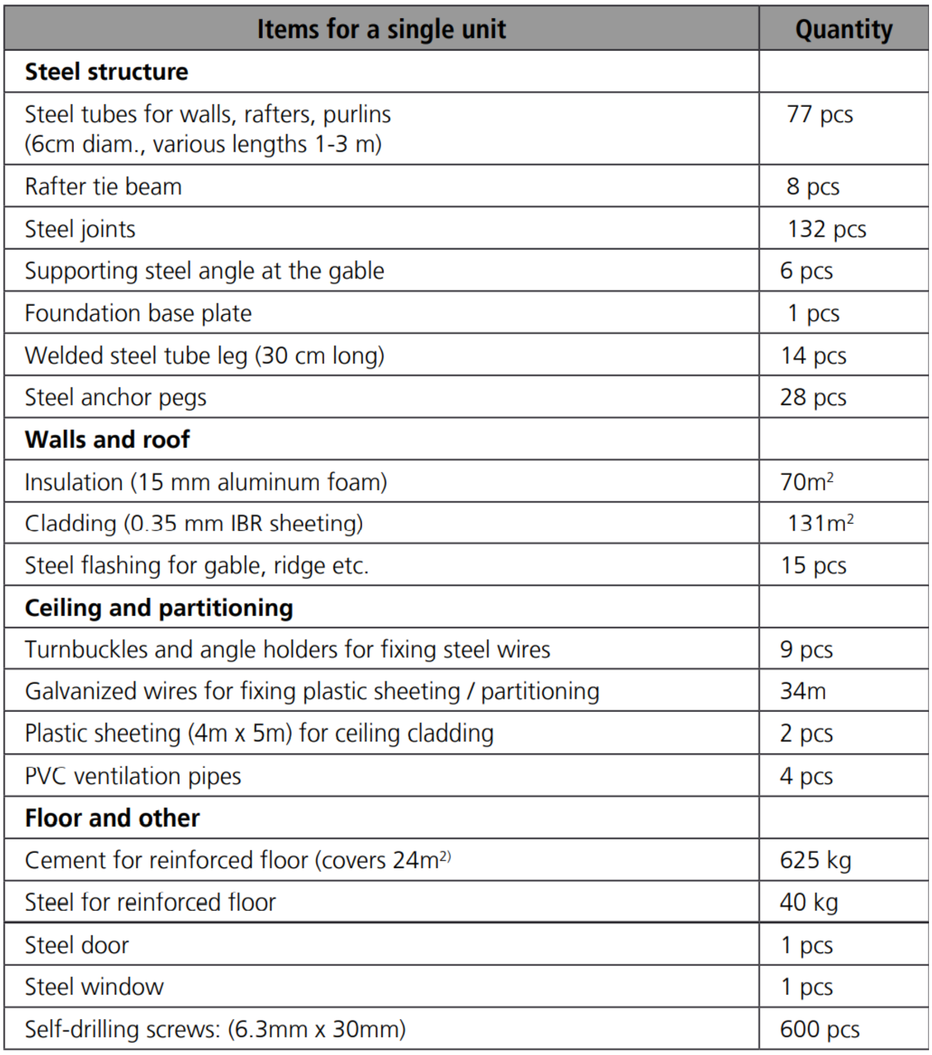
The project timeline for the construction of Azraq camp with T-shelter units was completed in one month and was as follows:

April 1st, 2013: Surveying of camp site begins, the Multi-agency T-shelter prototype construction and evaluation was completed on April 3rd. Between Implementation trial phase (1,000 units) lasting from 6 to 10 months.

The Camp officially opened with 4,200 units completed, which was achieved at the 14th month and the Planned handing over of 13,500 was completed T-shelter Units by February 2015, which is at the 24th month mark.

3.4.4 Design, Construction and Coordination:

The Shelter Sector Working Group and other sectors in Jordan worked together to develop the T-shelter design. Steel wires to allow for partitioning and address issues about gender privacy were among the aspects that were considered in the design. Additionally, accessibility specialists were consulted during the design of the entrance and door. Additionally, future WaSH facilities, like water and waste pipes, could be added to the T-shelters. The T-shelter design needed to be approved by the Jordanian government, and the agency collaborated closely with them. The rapid award of contracts was made possible by the Ministry of Public Works and Housing's participation in the procurement process. The development of steel-frame T-shelters was a response to the challenges encountered with prefab caravans used in refugee camps, such as Zataari. These challenges included costly and limited production due to specialist machinery required for sandwich-panel manufacture, slow production rates, environmental issues surrounding disposal, and expensive transportation that required a crane for loading/unloading, putting a significant strain on roads. In addition, During the winter, water leaks occurred from the plywood floors since they weren't sturdy. The T-shelter design, on the other hand, was developed to be adaptable and simple to make from available materials. It has a gable roof that improves ventilation, is packaged in a kit form that is easy to travel, store, and modify, and can be taken apart and put back together to serve as a return item. To make building shelters on hills or uneven ground easier, leg extenders were also included. The T-shelter design provides a larger living area and better flexibility for customization to meet the demands of the residents than prefab trailers, which needed stilts or level foundations. [37]



Items for a single unit	Quantity
Steel structure	
Steel tubes for walls, rafters, purlins (6cm diam., various lengths 1-3 m)	77 pcs
Rafter tie beam	8 pcs
Steel joints	132 pcs
Supporting steel angle at the gable	6 pcs
Foundation base plate	1 pcs
Welded steel tube leg (30 cm long)	14 pcs
Steel anchor pegs	28 pcs
Walls and roof	
Insulation (15 mm aluminum foam)	70m^2
Cladding (0.35 mm IBR sheeting)	131m^2
Steel flashing for gable, ridge etc.	15 pcs
Ceiling and partitioning	
Turnbuckles and angle holders for fixing steel wires	9 pcs
Galvanized wires for fixing plastic sheeting / partitioning	34m
Plastic sheeting (4m x 5m) for ceiling cladding	2 pcs
PVC ventilation pipes	4 pcs
Floor and other	
Cement for reinforced floor (covers 24m$^{2)}$	625 kg
Steel for reinforced floor	40 kg
Steel door	1 pcs
Steel window	1 pcs
Self-drilling screws: (6.3mm x 30mm)	600 pcs

Table 6: Quantities of Materials used for one t-shelter. [37]

The steel frame construction ensures durability and resistance to harsh weather conditions, while local unskilled labor can be trained quickly to assemble the T-shelters, creating employment opportunities. The T-shelter design represents a more sustainable and cost-effective solution to housing refugees, addressing many of the issues faced by the caravan design while providing additional benefits such as flexibility and customization options.

Figure 25: The inside conditions of T-shelters[37]

Key Findings:

In the Case of T-shelters, we can conclude from this case study in Jordan several points that will be divided mainly into Strengths and Weaknesses:

Strengths:

Quick Deployment: T-Shelters can be rapidly deployed in emergency situations, providing immediate relief to displaced individuals or communities.

Cost-effective: T-Shelters are often more affordable compared to traditional housing options, making them a viable solution for emergency situations with limited resources, this can be demonstrated here by the cost sheet, 14

Flexibility: T-Shelters can be designed to accommodate different needs and can be easily modified or expanded as required.

Mobility: T-Shelters can be easily transported and relocated to different areas, allowing for flexibility in responding to changing emergency situations.

Community Engagement: T-Shelters can promote a sense of community and solidarity among residents, as they often provide shared spaces and communal facilities.

Weaknesses:

Limited Comfort: T-Shelters are generally designed for short-term emergency housing and may lack the comfort and amenities of permanent housing, leading to potential physical and psychological stress for occupants.

Temporary Solution: T-Shelters are not intended to be a long-term housing solution, which means occupants may need to transition to permanent housing eventually, creating additional challenges.

Short Life Span: 4 years is a short life span, and it creates additional challenges and cost of re-deployment, as well as generates a lot of waste over time.

3.4.5 Case Study 4, Conventional Shelters: Nepal Earthquake

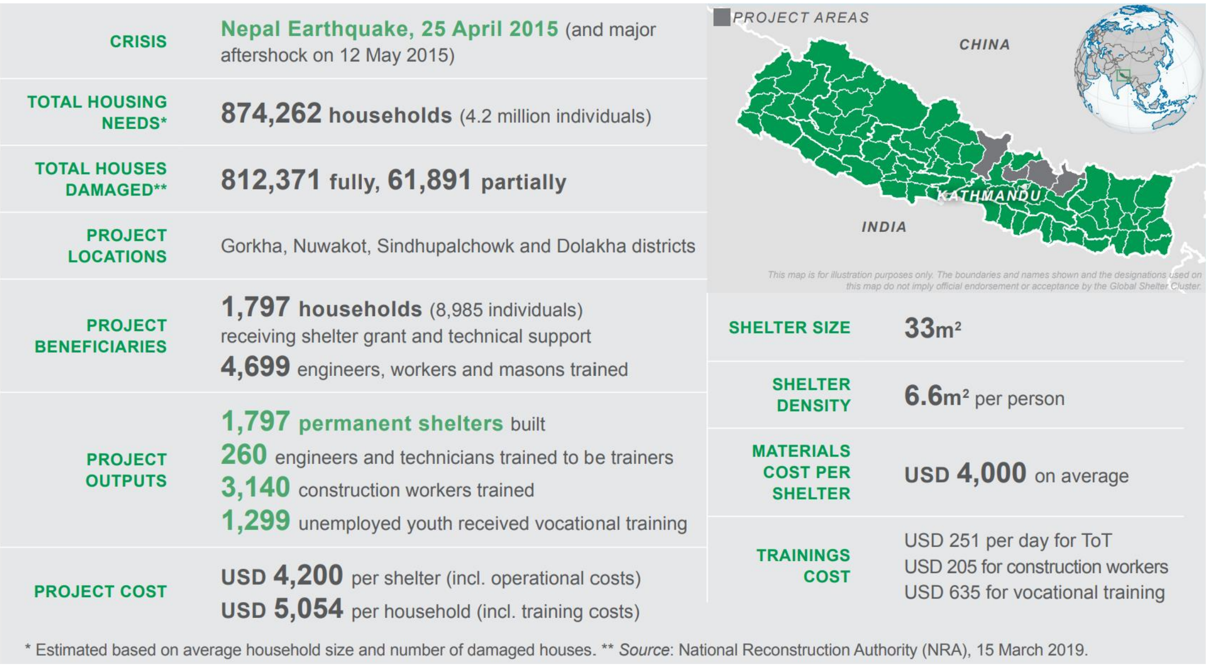
Figure 26:Nepal shelter project 2017[38]Nepal shelter project 2017[38]

The project was designed to help 1,797 homes in distant, earthquake-affected communities. It offered a stipend for housing reconstruction along with technical support to erect a building that is earthquake safe. The implementing organization provided more than 3,000 masons with training in code-compliant, earthquake-resistant construction methods using local resources. [37]

To address the significant dearth of skilled labor, more than 1,000 children in the project areas are receiving vocational training. To reach a larger segment of the impacted community outside of the specifically targeted families, a nationwide awareness campaign on the government reconstruction procedures and the Build Back Safer themes was also carried out.

A thorough study of earthquake shelters was carried out in response to the terrible Nepal Earthquake that struck on April 25, 2015. The study sought to address the crisis's immediate housing demands, which resulted from its devastating impact on an astounding 874,262 households, or over 4.2 million people. The initiative concentrated on four areas where the effects of the earthquake were particularly severe: Gorkha, Nuwakot, Sindhupalchowk, and Dolakha.[37]

The earthquake shelter research, which had as its main goal offering sustainable housing choices, was effective in helping 1,797 households. In addition, the project was essential in educating and equipping 4,699 engineers and employees with the skills they needed to properly participate in the reconstruction activities. These efforts led to the creation of 1,797 permanent shelters, which offered safe and stable housing for the afflicted families.



CRISIS	**Nepal Earthquake, 25 April 2015** (and major aftershock on 12 May 2015)
TOTAL HOUSING NEEDS*	**874,262 households** (4.2 million individuals)
TOTAL HOUSES DAMAGED**	**812,371 fully, 61,891 partially**
PROJECT LOCATIONS	Gorkha, Nuwakot, Sindhupalchowk and Dolakha districts
PROJECT BENEFICIARIES	**1,797 households** (8,985 individuals) receiving shelter grant and technical support **4,699** engineers, workers and masons trained
PROJECT OUTPUTS	**1,797 permanent shelters** built **260** engineers and technicians trained to be trainers **3,140** construction workers trained **1,299** unemployed youth received vocational training
PROJECT COST	USD **4,200** per shelter (incl. operational costs) USD **5,054** per household (incl. training costs)

This map is for illustration purposes only. The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the Global Shelter Cluster.

SHELTER SIZE	**33**m²
SHELTER DENSITY	**6.6**m² per person
MATERIALS COST PER SHELTER	USD **4,000** on average
TRAININGS COST	USD 251 per day for ToT USD 205 for construction workers USD 635 for vocational training

* Estimated based on average household size and number of damaged houses. ** *Source*: National Reconstruction Authority (NRA), 15 March 2019.

Figure 27: Nepal shelter project Key figures[37]

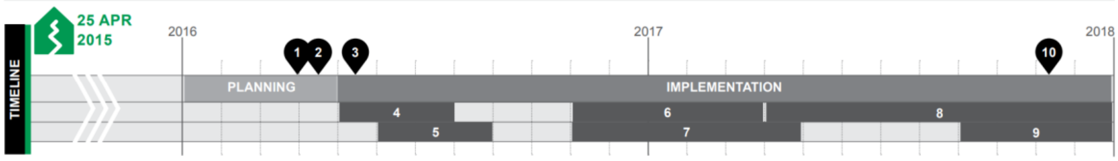


Figure 28:Timeline: The project consisted of several phases and in total took around 2 years to complete.[37]

The initiative gave educating 260 engineers and technicians to become trainers themselves a high priority because it understood the significance of knowledge transfer and capacity building. By increasing the number of qualified professionals who are prepared to handle future emergency scenarios, this step aims to assure the initiative's sustainability.

It is important to note that the earthquake shelter study had project costs of 5,054 USD per home, including the costs associated with the required training. The 33 square meter shelters that were built as a result gave the impacted families enough space to live. Additionally, the shelter density met an excellent standard, with roughly 6.6 square meters per person, ensuring the residents' comfort and safety.[37]

Overall, the earthquake shelter study in Nepal was a sizable effort in response to the emergency and provided great relief to many impacted people. The project aims to support the afflicted communities' long-term rehabilitation and resilience by constructing permanent shelters, training engineers and technicians, and upholding strict requirements for shelter size and density.

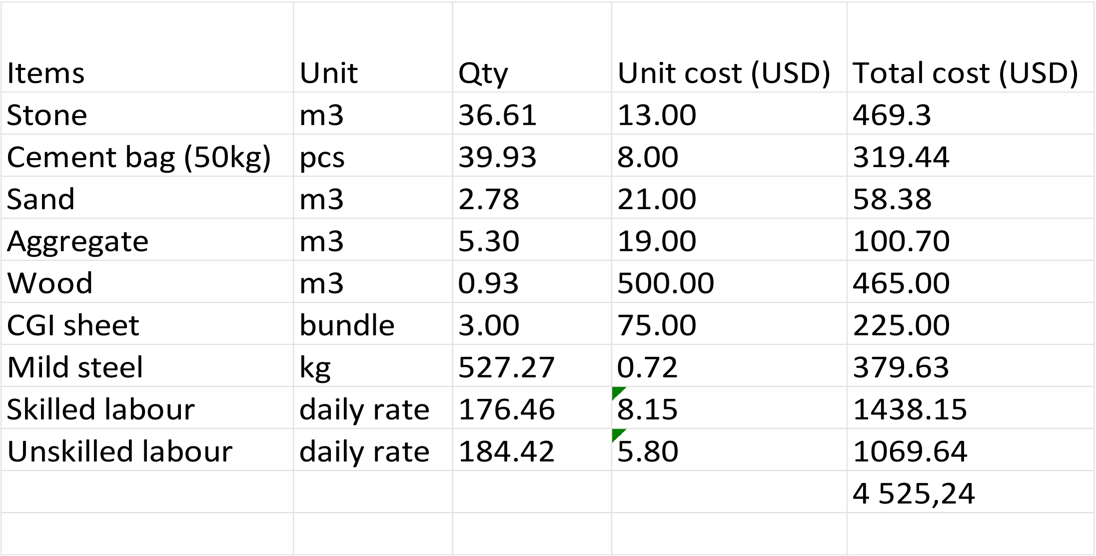
When the emergency response was wrapping up and the Shelter Cluster was being phased out eight months after the earthquake, the government formally established the National Reconstruction Authority.

The ability (NRA) to oversee the reconstruction efforts. In order to help residents construct permanent homes, the government offered funds that were subject to certain conditions. Construction worker training was given priority due to the dearth of suitably skilled labor for extensive rehabilitation. Retrofitting guidelines and training were initially not given priority.

The group created local dwelling designs that were more economical than those in the government's design catalog, and these ideas were then approved alternatives and distributed. [37]

The earthquake-resistant components were the focus. These included the selection of quality construction materials and workmanship, the use of light materials in gables and roofs, the use of vertical and horizontal seismic bands, and the proper scale, proportion, and height of the buildings.

The typical construction of dwellings in earthquake-affected areas was stone masonry using mud mortar and plaster, which was then covered in corrugated iron sheets or, on rare occasions, slate roofs. Houses typically had three floors and a footprint between 28 and 65 square meters. The majority of people lived on the ground floor, using the first floor for sleeping and the attic to store their crops. The new designs were frequently smaller than conventional homes in order to reduce construction costs and adhere to building codes. It was simple for them to adapt, though, as the majority of the targeted households had modest family sizes. Larger families opted for alternative designs with bigger floor plans, increased the attic level (without jeopardizing structural integrity), or utilised the transitional shelters constructed in earlier stages of the response for storage or to house livestock. Conventional shelters costs between materials and labour are shown in Table 5.



Items	Unit	Qty	Unit cost (USD)	Total cost (USD)
Stone	m3	36.61	13.00	469.3
Cement bag (50kg)	pcs	39.93	8.00	319.44
Sand	m3	2.78	21.00	58.38
Aggregate	m3	5.30	19.00	100.70
Wood	m3	0.93	500.00	465.00
CGI sheet	bundle	3.00	75.00	225.00
Mild steel	kg	527.27	0.72	379.63
Skilled labour	daily rate	176.46	8.15	1438.15
Unskilled labour	daily rate	184.42	5.80	1069.64
				4 525,24

Table 7:Average costs for a shelter with an average area of 33m2.[37]

In the next Section, A proposed 3d printed shelter design would be presented , which can be used as a module or a porotype design for semi-permanent shelter cases. Cost estimation as well as project time estimation would be concluded from the proposed Design. Three scenarios will be presented and compared using a cost model. Key findings will be presented.

3.5 3d Printed Shelter Design Simulation:

The following Shelter was designed by the researcher and will be used to provide a general idea about the time and cost needed for one shelter to be constructed using additive manufacturing technology. The simulation will include the types of walls designed, the number of laborers and the type of printer chosen. The simulation will tackle two comparisons, the first one is for cost per m2 for a 3D printed shelter compared to other conventional shelters mentioned in the case studies, and the second comparison is for the same design shelter while changing the method of construction. The aim is to get an idea on where does as a case study comparison to the other Shelters provided in the study, as well as how does change of materials and construction methods affect the cost and construction time. For the second part of this shelter design simulation comparative study, only the exterior walls and interior walls is what the analysis will be based on. The roof, slabs, windows and doors are the same in the three cases and for that reason , they were disregarded for the second part of the comparison. The researcher will develop a shelter design simulation for three scenarios : Shelter built with conventional methods and shelter built using 3DCP and a third shelter built with a combination of both methods. List of materials used with cost will be provided, as well as labor cost and time needed to complete for both scenarios. The results will be compared, and a conclusion will be made.
For the cost and time analyses, case data from two experimental 3DCP real-world usage (Singapore and Denmark) were collected and adjusted to the area in question [38] .Other data for cost and time estimation was gathered from the Saudi national index[39] for construction costs for the year 2023. It is to be

acknowledged that costs differ for each country but nevertheless a general idea for cost comparison can still be developed from the results obtained.

The shelter:

The shelter has a basic design, with an area of approximately 36 m2, a rectangular 3,635 mx 10 m shape with one external door and three windows. It fulfills its basic function objectives and accommodates up to four people. It contains one big room with a kitchenette and one bathroom with a shower. The exterior walls are printed with double layers.

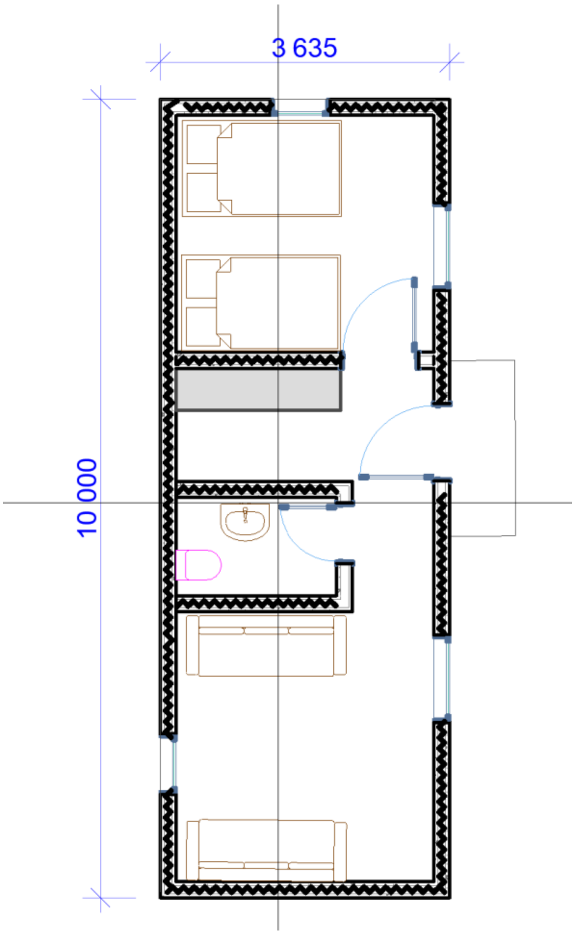


Figure 29: Proposed Shelter Design

Scenario 1: S1 3DCP

Exterior Walls:

The proposed shelter's exterior wall was built utilizing 3D printing without the use of additional formwork materials. The external hollow core walls, which are three times stronger than external walls constructed with traditional concrete, are gradually constructed out of layers of self-compacted concrete. Additionally, these walls can still be altered to accommodate infrastructure pipes, electrical and plumbing fittings, and more [35]. The nozzle first constructs the outside borders with a thickness of 5 cm, then it builds the central axes with a thickness of 2.5 cm, and finally it builds the zigzag line in the two sides of the central axes with a thickness of 2.5 cm to ensure the coherence of the wall (Figure 18).

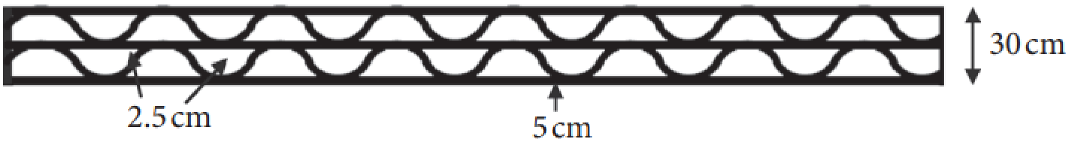


Figure 30:Exterior walls of the proposed shelter.

Interior walls:

Two types of inside walls for the proposed shelter are created using 3D printing: the first is a solid-core wall with a 10 cm thickness. the second

type is a hollow-core wall with a 15 cm thickness, where the extrusion nozzle constructs the exterior edges with a 2.5 cm thickness before constructing a 2.5 cm thick zigzag line to guarantee the integrity of the wall (Figure 22).

Figure 31: Interior walls for the proposed design

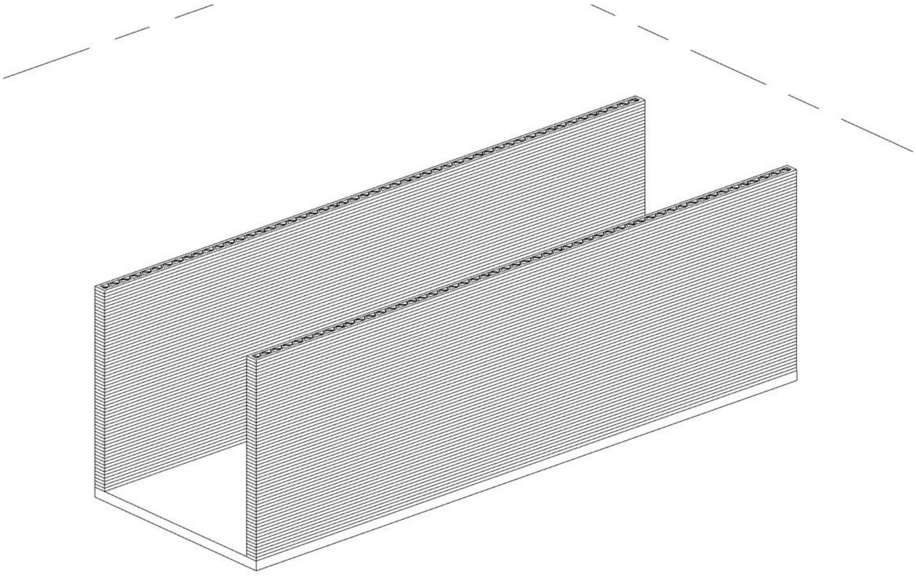


Figure 32:3d View ond the exterior walls

The 3Dprinter:

The printer chosen for this simulation is the IRB 8700 robotic combined with a concrete pump and nozzle. The choice of this model over the gentry printer is due to the size of the projects which is suitable for this application, and in addition, due to logistics reason, for example, transportation of this robot to the site is much easier than transporting the gantry printer.The disadvantage of this robot printer is the limited reach of the arm, which will require the workers to adjust the position of it twice in order to complete the shelter.

Scenario 2: Conventional methods for walls

Exterior walls:

In this Scenario, the proposed exterior walls would be made of a double layer of Concrete masonry units. Separated by a layer of air. At the four corners reinforced 30x30 cm reinforced concrete columns would be implemented to hold the roof.

Interior walls:

For interior walls, one layer of 10 cm CMUs would be used. Lintels would be implemented above openings.

It is assumed that 4 laborers are needed for each Shelter in this scenario.

Scenario 3 : S3

Exterior Walls and interior walls are 3d printed using ready to print concrete, the columns and lintels are manually casted with reinforced concrete.

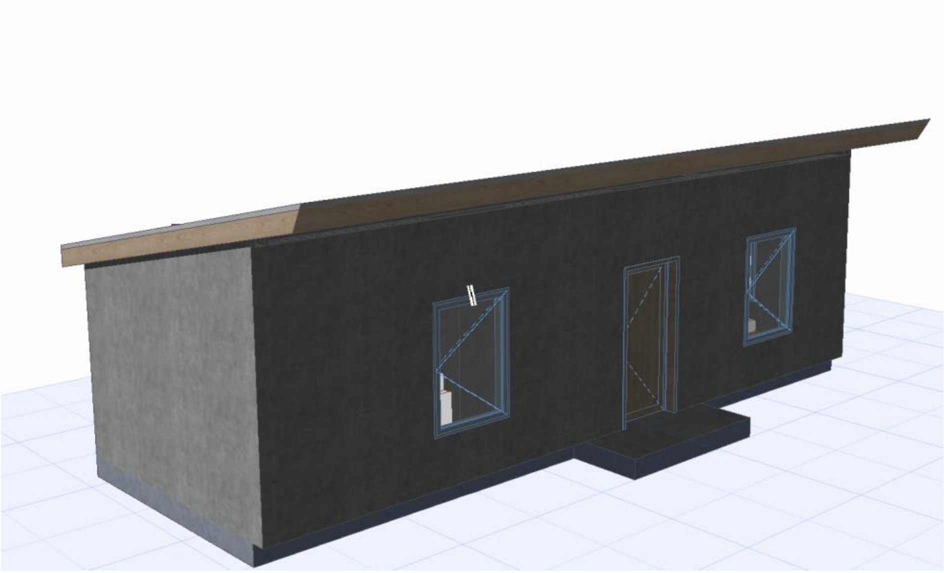


Figure 33:3d View of the proposed shelter.

4 Results:

Time is a crucial criterion when erecting shelters. Vulnerable people are waiting to occupy their new safe places as soon as possible. If we compare the cases, we find out the following:

4.1 Cost Comparison With conventional shelters.

-Nepal shelters: In the Nepal shelter case 1797 shelters were erected in a total span of 2 years or 730 days. Of course, this was possible due to the high number of engineers and architects and labors involved in the project, 3140 labors and an additional 240 engineers and 1299 youth that received vocal training were also helping. Cost per shelter =121 USD per m2

With simple mathematics we can find that an average of approximately half a working day per shelter is the average time if construction or 4 hours per shelter.

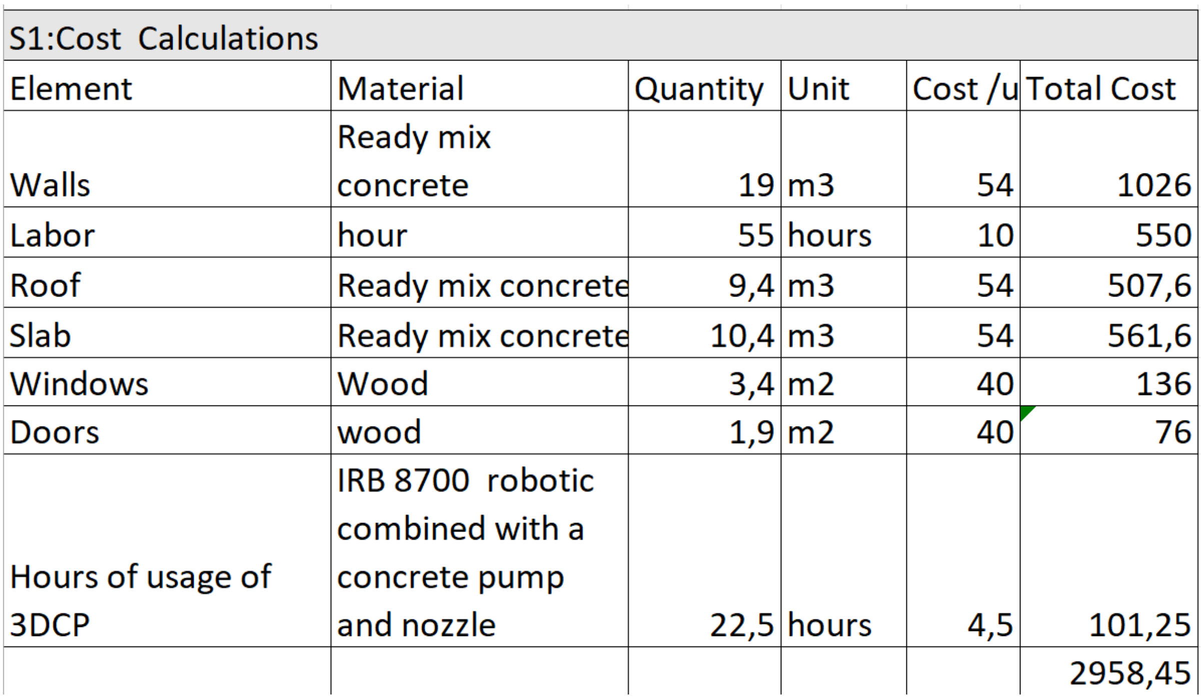
-For Jordan shelter case, if we follow the timeline, the workers were able to erect 1000 T-shelters fin 4 months or 120 days, with an average of about 9 shelters per day. If we assume that the working time was 8 hours a day. Each shelter needed 1 hour approximately on average to be erected. He we have to consider that t-shelters are temporary solutions and are not a good option for long term options as the average lifetime of a t shelter is around 3 years. But this allows us to conclude that in terms of time efficiency T-shelters are a great option.

Cost per shelter =97 usd per m2

-3DCP: From time calculations, one shelter needs 24 hours of printing time. In general, this required time is considered short considering that the shelter is concrete, durable and erected from scratch. However, this can be seen as excessive time to complete one shelter when compared to the other cases. But just as other cases had thousands of workers and laborers, more than a printer can be used to print the shelters which can compensate for the time needed. And the advantage is that way less labor is needed to complete one shelter and the process is automated.

Materials and Labors comparison between the three cases can be seen in the fig 36.

The cost of the entire 3DCP shelter is 2958 euros or 82 euros/m2.



S1:Cost Calculations					
Element	Material	Quantity	Unit	Cost /u	Total Cost
Walls	Ready mix concrete	19	m3	54	1026
Labor	hour	55	hours	10	550
Roof	Ready mix concrete	9,4	m3	54	507,6
Slab	Ready mix concrete	10,4	m3	54	561,6
Windows	Wood	3,4	m2	40	136
Doors	wood	1,9	m2	40	76
Hours of usage of 3DCP	IRB 8700 robotic combined with a concrete pump and nozzle	22,5	hours	4,5	101,25
					2958,45

Table 8:Cost of the entire 3d printed shelter using S1

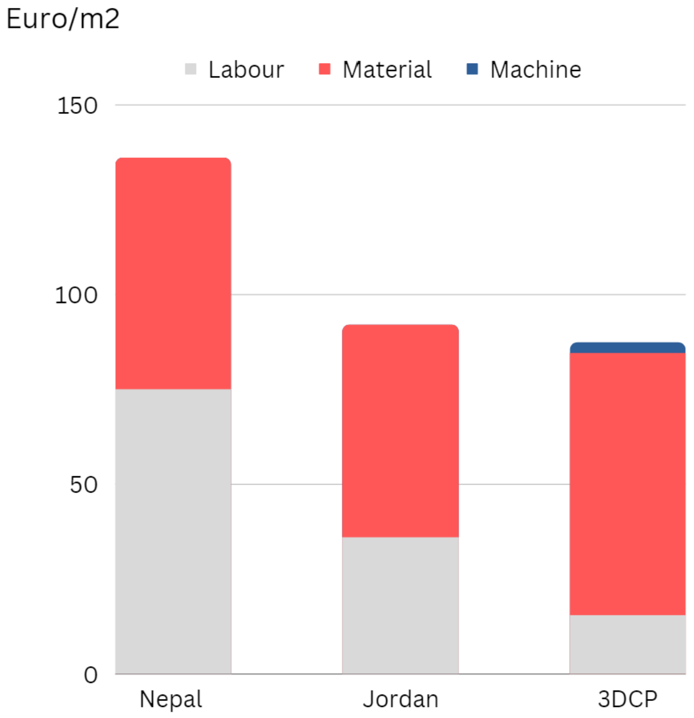


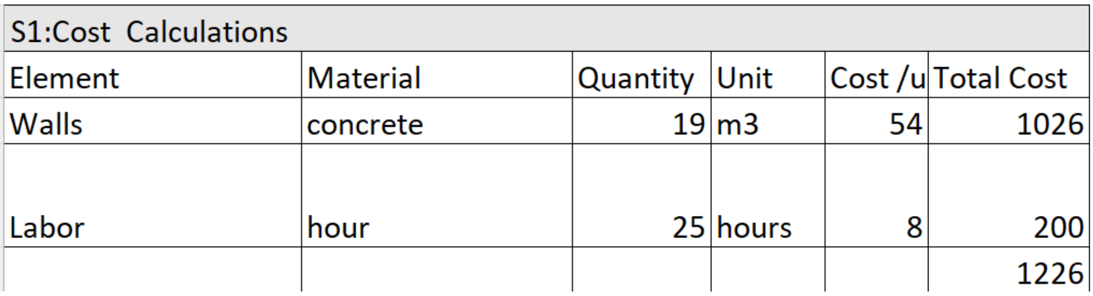
Figure 34:Cost Comparison for the three cases per m2

4.2 Cost Comparison for the three scenarios

To add value to the research, a cost comparison and a time process comparison between the three scenarios is listed in the next section.

Scenario1 :

Cost of material and labor: For the material cost in the Scenario 1, It is assumed that 2 labors are needed on site to operate the robotic arm and the pump, and do the mounting and unmounting of the machine in order to complete the printing process, everything else is automated. The Labor and material costs rate has been taken using the Saudi Authority for Statistics[39] numbers as a benchmark and would be adjusted based on the country where the project is in. Time: With printing speed of 200mm/s , and using detailed calculations, it is concluded that 12,45 hours of total printing are needed to complete the exterior and interior walls of the shelter. The costs are showcased in the table below.



S1:Cost Calculations					
Element	Material	Quantity	Unit	Cost /u	Total Cost
Walls	concrete	19	m3	54	1026
Labor	hour	25	hours	8	200
					1226

Table 7: Cost Estimation based on quantity of materials taken from the BIM model.

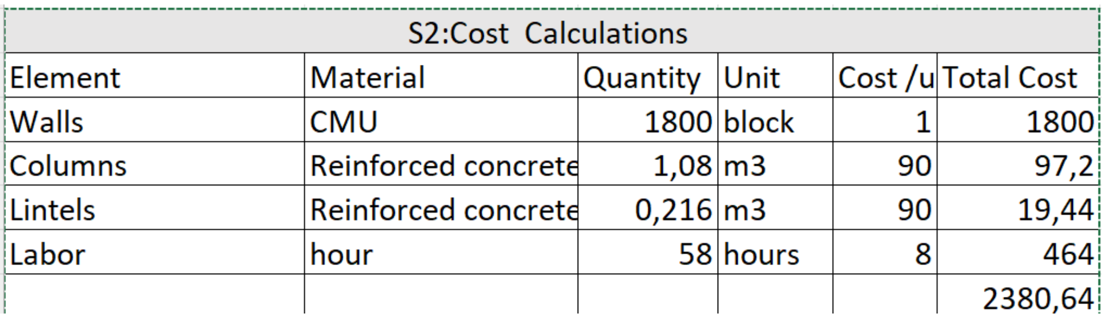
Additionally,What we can learn from the Tecla case study, in the case where natural earth can be provided from the local site of the camp, the material cost can technically drop to 0. This gives 3DCP a huge advantage over the other cases. This hypothesis is dependent on each case and for this one, ready mix concrete will be used to provide the comparisons.

The time process analysis was made only for the exterior and interior walls of the shelters, due to that the slabs and roof can be integrated as non-printed elements. The total printing time of all the walls based on a speed of 200mm/s was a total of around 44848 seconds or 12,45 hours of printing time per shelter. The detailed calculations is showcased in table 8 below.

Scenario 2:

For Cost of material and Labor, the calculated man hour for the conventional construction of the shelter was around 60 manhour[40] for the exterior and interior walls. That equates to 4 workers working 2 days.

For cost, The labor cost in this scenario is 480 euros, while the material cost also defers from S1 with adding the CMU units and the reinforced concrete. Detailed figures are show in the table below. The cost of the walls per m2 in this scenario is 68 euros per m2 of shelter.



S2:Cost Calculations					
Element	Material	Quantity	Unit	Cost /u	Total Cost
Walls	CMU	1800	block	1	1800
Columns	Reinforced concrete	1,08	m3	90	97,2
Lintels	Reinforced concrete	0,216	m3	90	19,44
Labor	hour	58	hours	8	464
					2380,64

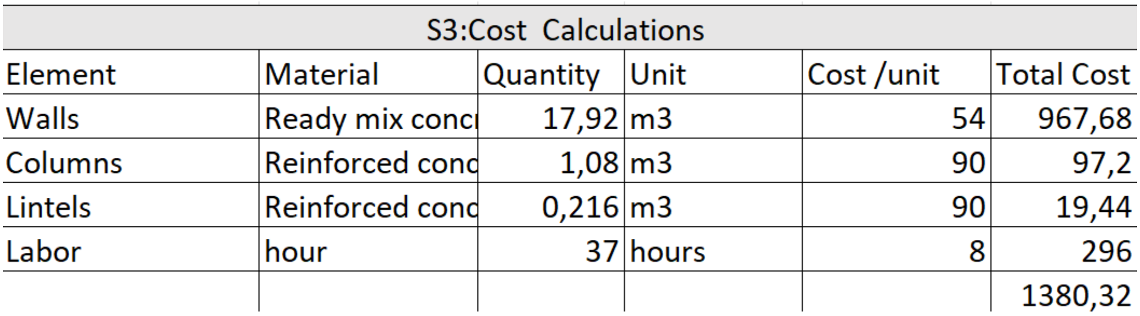
Table 8:Costs of walls for S2

Scenario 3:

For this Scenario, the cost of walls falls in between the two previous scenarios.

As for the time, around 57 manhours are required for 1 shetler, 25 hours for the printing workers and 23 hour for the formwork and concrete casting.

The costs are shown in the table below.



S3:Cost Calculations					
Element	Material	Quantity	Unit	Cost /unit	Total Cost
Walls	Ready mix conc	17,92	m3	54	967,68
Columns	Reinforced conc	1,08	m3	90	97,2
Lintels	Reinforced conc	0,216	m3	90	19,44
Labor	hour	37	hours	8	296
					1380,32

Table 9: Walls cost for S3

In terms of cost, the analysis shows that the proposed 3DCP shelter design, is comparable to the semi-permanent shelter that was built using traditional methods in Nepal. If we dig deeper, we can see the influence of Labor on Traditional built Shelter cost compared to the minimal influence in the case of 3DCP. (Fig 22)

Predictably, 3DCP will cost more than T-Shelters but the comparison here is between Temporary shelters that have a lifetime of 2-3 years and do not offer as a high degree of protection as 3DCP Shelter.

In addition, these types of Shelters generate high rates of waste, while the 3DCP produces zero or minimal waste.

Time Analysis:

For the Shelter design Simulation:

Each scenario provided different results in terms of costs and time analysis.

The chart shows the cost distribution between labor and materials in the 3 scenarios.

S1 has the lowest labor cost while S2 has the highest labor and materials cost as well.

This indicates that 3DCP cut the costs on labor dramatically, as well as materials.

S3 Is a combination of both methods and the cost falls in between.

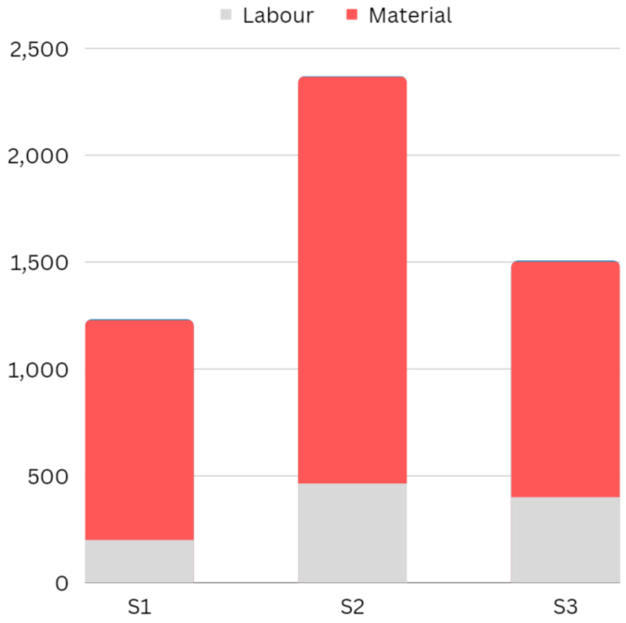


Figure 35: Cost distribution between labour and material for the 3 scenarios

Time:

As for Time, The fastest erected shelter was S1, with a total completion time for walls 25 manhours to complete. S3 is the second fastest with 37 manhours and S3, the conventional method was the longest with 58 manhours to complete.[40] The results are shown in the chart below.

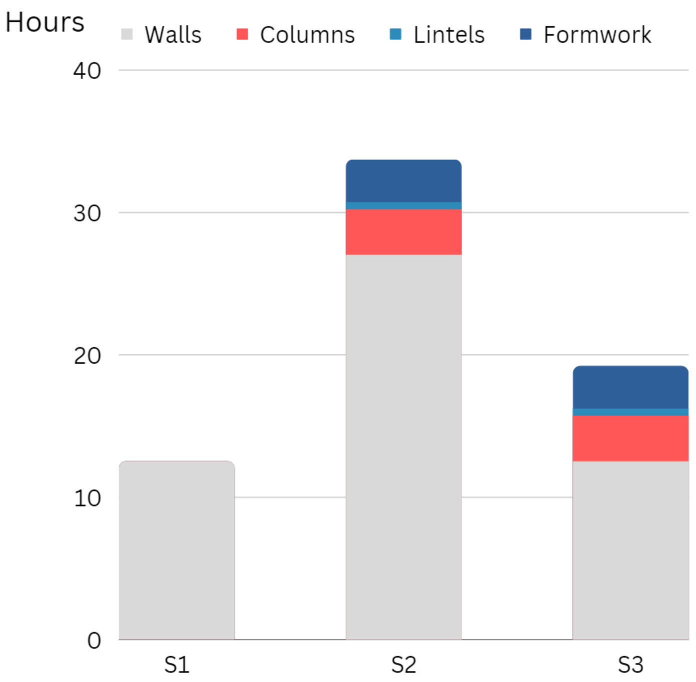


Figure 36:Time process distribution between activities for the 3 scenarios

5 Discussion and Conclusion

Construction is one of the least automated industries, and productivity has been stagnating until recently. However, the advent of new tools like 3DCP and digital transformation in general promise to disrupt the status quo. In this study, the researcher used a variety of various Shelter case studies and choices to examine the time and cost effects of 3DCP compared to traditional shelter construction methods. The investigation showed that 3DCP offers chances to carry out sophisticated designs without incurring additional costs. Concrete printing enables multipurpose construction design, which means that a wall can be planned and built in a way that makes it both a space separator and an insulator, due to its internal shape.

The comparisons made in the previous chapter were to provide information on whether concrete printing the shelters a viable solution in comparison to T shelters and conventional shelters can be. The results proved that technology has a great potential to provide solutions due to its speed and ease of construction. In terms of materials, it provides the lowest costs compared to the other solutions. It can also be argued that it produces close to zero waste, the amount of material needed is calculated and purchased, and unlike T-shelters which produce waste every 3-4 years because of their short life cycle and the need to be replaced, 3DCP shelters are semi-permanent to permanent structures. Labor is still needed to provide support and orientation and supervision for the printing robots, nevertheless compared to conventional methods, the dependence on workers is reduced. However, high-level training is needed to operate the machines, and this could be a downside for this technology.

One of the reasons why 3DCP hasn't severely affected the building sector yet is because it is so heavily regulated. Construction regulations vary throughout nations, states, and provinces. Additionally, approval procedures differ based on the position geographically. There are currently no standards that cover the use of 3DCP in building [41] which makes obtaining regulatory permits difficult. Most building codes and procurement guidelines do not take 3DCP technology into account [42]]; as a result, 3DCP businesses adhere to general, already-established construction requirements in their individual regions. Because of this, the approval process for 3DCP building is more drawn out than it is for conventional construction. However, For Shelters, regulations can be mild or none-existent and this is an additional reason to use this technology.

The goal of the current study was to determine whether additive manufacturing for construction methods may address the need for sustainable emergency housing and shelters. In order to give context for the situation in the world, which is plagued by conflicts and natural calamities, it was necessary to find a solution for long-lasting shelters. The literature evaluation then continues to investigate whether the printing media are sufficient and how technically prepared is this technology for use. To do this, it first provided background information about the region of the middle east's current position with regard to displacement and the need for refuge. The method of 3D printing was then explained, along with its advantages, drawbacks, and range of potential applications for the building sector. The case studies chapter allowed for a further understanding of how these techniques are being subjected to field applications and what are the common shelters used in the area and in general and some of the shortcomings of the existing solutions. The methodology chapter continues with a design of a 3d printed shelter created by the researcher and a scenario simulation to estimate the money and duration costs if such a solution would be implemented in shelter camps.

Shelters and Displacement:

The research's findings regarding the current scenario regarding displacement showed and emergency housing,specifically in the MENA region,showed that it is a very complicated issue that affects a significant portion of the region's population as a result of wars or natural disasters. It demonstrated that the shelter options offered are frequently deficient in one or more areas, such as security, long-term viability, or completion time. It is important to comprehend a household's economic status, cultural background, and hierarchy of demands, as well as to ensure access to essential services and to provide security and stability to those who have been forcibly relocated. Most of these problems cannot be resolved by the existing conventional shelter options, which is where the promise of implementing 3d printing comes into the picture.

Shelters and Additive manufacturing:

In terms of Additive Manufacturing, the research showed that this technology has huge potential in the construction industry. It is being implemented in some cases of social housing already and has a variety of ranges of applications. New innovations and research are also being made in order to develop its potential into new materials other than printable concrete, for example raw earth was seen in the case study made around Tecla Project.

The other case studies and design simulation showed that 3d printing the shelters offer advantages of durability above the t-shelters and cost and time above the conventional permanent and semi-permanent shelters like shelters made from cast concrete and masonry.

In this case, the main cost was made from materials and the labor cost was minimal, compared to other conventional building methods.

To conclude, this research set a primary positive general assessment about the use of 3d printing technology for humanitarian causes like shelters and social housing, it provided the reader with a framework of additive manufacturing in the construction sector and proved that this technology when compared to other shelter methods proves to be superior, in terms of saving cost and time. However, more testing on a bigger scale is still needed to prove the scalability of this technology. In addition, The lack of specialized skilled workers in this industry and lack of testing and technology implementation in the region raises question on the implementation time of this potential solution on a bigger scale.

Declaration of Authorship

I hereby declare that the attached master's thesis was completed independently and without the prohibited assistance of third parties, and that no sources or assistance were used other than those listed. All passages whose content or wording originates from another publication have been marked as such. Neither this thesis nor any variant of it has previously been submitted to an examining authority or published.

Berlin, 07.07.2023

Location, Date

Signature of the student

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Research questions guidelines

Objective	Research Question	Indicator	Output	Source
Understand the current shelter situation in the MENA region	What are the current sheltering solutions offered in the MENA region?	Area of the shelters, typed of shelters, degree of security	The link between the the offered shelters and security, quality of living	UN reports, scientific articles
	What are the main issues?	Quality deficiency, prolonged time to complete	There is a lack of security and non-sustainable solutions	UN reports
	What role do private and public entities play	Social Aid programs, number of governments involved	Most shelters are provided from international organizations	UN reports
	Why are shelters really important in the MENA	Number of displacements from war or natural disasters	Highest number globally	UN reports
Understand in general robotics in the construction industry	How do robotics and 3d printer work	Data exchange, process development	Relation between operators and robots,	Science articles, google scholar
	How can the construction industry benefit	amount of savings in labour,time saving, waste reduction amount		
	Main threats of robots in construction	Effect on employment	Special skilled labour needed to operated the machines and monitor the work	Google Scholar, Scientific articles
	Which are the technologies available specifically for the industry?	List of technologies	D-shape, Concrete printing	Google Scholar, Scientific articles

Understand additive manufacturing	What materials can be used?	List of Materials	Concrete, compacted earth, Polymers etc.	Google Scholar, Scientific articles
	What affects the quality of 3d printing and How can the process be improved	Open time, Layer adhesion, Pumping speed, density, durability		
Understand the potential of use of AM in shelter projects in the middle east	How does AM impact shelter projects in the Middle east and north Africa	Quality of Shelters, People employed, Time impact of projects, Waste impact, Safety	Benefits: Less Time, Less cost, More safe building sites, More reliable shelters, Waste reduction. Challenges: Unemployment, Price of equipment, High skills needed, Materials reliability	Swot Analysis, Scientific Articles, Google Scholar, Case studies
Shelter case study Simulation	How does conventional methods and 3d printing affect the cost and time process of a shelter	Cost estimation, Time estimation	Cost comparison: Materials and labor, Time comparison: Conventional vs 3d Printing	Revit, Google scholar, scientific articles
Case studies of 3d printed structures	How applicable is it and what materials can be used	Case Studies	Social Housing projects, new material projects	Google Scholar, Scientific articles
Case studies conventional methods	What are the weaknesses and challenges and strenghts of conventional shelters	Case Studies	T-shelter case studies, conventional construction shelter case study	Google Scholar, Scientific articles

[Appendix 2](#)

[Appendix 3](#)