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SUSTAINABLE 3D PRINTING FOR POST-DISASTER RECONSTRUCTION

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ABSTRACT

Natural disasters such as earthquakes, hurricanes, and floods can have devastatingimpacts Sustainable 3D Printing for Post-Disaster Reconstruction
technology has emerged as a promising tool for post-disaster reconstruction, offering a flexible,affordable, and eco-friendly alternative to traditional construction methods. This
article explores the potential of sustainable 3D printing for post-disaster reconstruction, drawingon case studies from around the world, including 3D printed houses, bridges, and critical supplies. The article also provides recommendations for applying sustainable 3D printing in Turkey city after an earthquake, focusing on the importance of conducting a needs assessment, engaging key partners and stakeholders, developing a sustainability plan, and monitoring progress. The findings and insights from the article highlight the challenges and opportunities associated with sustainable 3D printing technology and its potential to contribute to more resilient, sustainable, and equitable post-disaster recovery efforts.

Keywords:
Sustainable 3D printing, post-disaster reconstruction, disaster relief, Turkeycity, case studies, sustainability.

INTRODUCTION

Natural disasters have become increasingly common and severe in recent years, affecting millions of people and causing billions of dollars in damage worldwide (United Nations Office for Disaster Risk Reduction, 2021). In the aftermath of a disaster, the immediate priorities are often to provide food, water, shelter, and medical assistance to affected communities. However, the long-term challenge of rebuilding damaged infrastructure and homes can take years or even decades, especially in low-income and vulnerable communities (Morrow & Mock, 2014). This is where sustainable 3D printing technology comes in, offering a potentially transformative tool for post-disaster reconstruction that is faster, cheaper, and more eco-friendly than traditional construction methods. This paper explores the potential of sustainable 3D printing for post- disaster reconstruction, drawing on case studies from around the world, and provides recommendations for applying this technology in Turkey city after an earthquake.
Background and context for the use of 3D printing in post-disaster reconstruction Natural disasters such as earthquakes, hurricanes, and floods can cause immense damage to infrastructure and communities, resulting in significant economic, social, and environmental impacts. Post-disaster reconstruction is a critical process that involves rebuilding and restoring Essential infrastructure, housing, and community services to support the recovery and resilience of affected communities. However, traditional construction methods for post-disaster reconstruction are often slow, costly, and unsustainable, and can exacerbate the environmental and social impacts of disasters. In recent years, sustainable 3D printing has emerged as a promising technology for post-disaster reconstruction, offering several advantages over traditional construction methods. Sustainable 3D printing enables the production of customized and locally-sourced solutions, which can be more resilient and sustainable than imported materials. Additionally, sustainable 3D printing can reduce waste, energy consumption, and greenhouse gas emissions, making it an eco-friendlier alternative to traditional construction methods.
The purpose of this article is to explore the feasibility and potential of sustainable 3D printing for post-disaster reconstruction, with a focus on the case of Turkey city after an earthquake. The paper will draw on case studies from around the world to highlight the benefits and challenges of sustainable 3D printing for post-disaster reconstruction and provide recommendations for applying the technology in a responsible and equitable manner.
The significance of this paper lies in its potential to inform and inspire policymakers, practitioners, and researchers

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involved in post-disaster reconstruction efforts. By highlighting the lessons learned and providing recommendations for applying sustainable 3D printing in Turkey city, thispaper can contribute to more resilient, sustainable, and equitable post-disaster recovery efforts that benefit affected communities and the environment.

This article argues that sustainable 3D printing has the potential to revolutionize post-disasterreconstruction efforts by providing a faster, cheaper, and more eco-friendly alternative to traditional construction methods. However, to fully realize the potential of sustainable 3D printing for post-disaster reconstruction, it is necessary to address the challenges and limitations of the technology and ensure that it is used in an equitable and responsible manner. Drawing on case studies from around the world, this paper will highlight the lessons learned and provide recommendations for applying sustainable 3D printing in Turkey city after an earthquake, with the aim of creating more resilient, sustainable, and equitable post-disaster recovery efforts that benefit affected communities and the environment.

I. Sustainable 3D Printing Technology:

A. Overview of Sustainable 3D Printing Technology:

Sustainable 3D printing technology involves the use of additive manufacturing techniques to create 3D objects from a range of materials, including bioplastics, recycled plastics, and natural fibers. The process involves the creation of a digital model of the object, which is then convertedinto a series of instructions for the 3D printer to follow. The printer then deposits material layer by layer until the object is complete. Sustainable 3D printing can be used to produce a wide range of objects, including construction materials, prosthetics, and medical devices. In post- disaster reconstruction, sustainable 3D printing has the potential to provide quick, customizable, and locally sourced solutions to meet the urgent needs of affected communities.

B. Benefits and Limitations of 3D Printing in Disaster Relief and Reconstruction:

Sustainable 3D printing technology offers several benefits for disaster relief and reconstruction efforts. One of the primary benefits is speed. 3D printing can produce objects quickly and on demand, allowing relief organizations and communities to respond rapidly to urgent needs. Another advantage of 3D printing is the ability to produce customized solutions that are tailored to the specific needs of communities. Additionally, sustainable 3D printing canreduce waste, energy consumption, and greenhouse gas emissions compared to traditional construction methods, making it a more sustainable option. However, there are also some limitations to the technology, including the high cost of equipment and materials, the need for specialized training, and limitations on the size and complexity of objects that can be print

C. Key Considerations for Sustainable 3D Printing Projects:

To ensure the success and sustainability of 3D printing projects in disaster relief and reconstruction, it is important to consider several key factors. One consideration is the selectionof appropriate materials. The materials used in 3D printing should be locally sourced, sustainable, and able to withstand the environmental conditions of the disaster-affected area.

Another consideration is the availability of skilled personnel to operate and maintain the 3D printers. It is also important to consider the social and cultural implications of introducing newtechnology in disaster-affected areas and to ensure that local communities are involved in the decision-making process. Finally, it is essential to ensure that 3D printing projects are implemented in an equitable and responsible manner, with a focus on meeting the needs of themost vulnerable members of the community

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II. Case Studies:

A. "3D Printed Houses for Post-Disaster Reconstruction" by ICON and New Story: One of the most significant examples of sustainable 3D printing technology in post-disaster reconstruction is the collaboration between ICON and New Story to create 3D-printed homes. In2018, the two organizations partnered to build a community of homes in Tabasco, Mexico, for families who lost their homes in a devastating earthquake.

Fig.1 The first two 3D-printed homes in Tabasco sit side by side on Lavacrete

The homes were constructed using a large-scale 3D printer that can create walls up to 28feet long, 8.5 feet tall, and 10 feet wide. The process involves the use of a proprietary 3D printing technology that allows to produce homes with unique designs, unlike traditional construction methods. The 3D printing process for each home takes around 24 hours, significantly reducing the time and labor required for traditional construction methods.

Fig.2 ICON's Vulcan II printer prints homes atop a cement pad.

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The homes are designed to be affordable, safe, and sustainable. They are built with locally sourced materials that are tested and approved for strength and durability, and the use of3D printing technology allows for a reduction in waste and environmental impact. Each home isalso equipped with solar panels to provide electricity, and the design is optimized for natural ventilation to reduce the need for air conditioning. The homes are built to meet the InternationalBuilding Code, ensuring that they are safe and structurally sound.
The partnership between ICON and New Story has shown that 3D printing technology can be aviable solution for post-disaster.

Fig.3 Print Operator Connor Namura Using ICON'S Vulcan Construction System in Mexico

Emerging Objects is a design and research studio that has been working to implement sustainable3D printing technology for disaster relief efforts in Haiti. Following the catastrophic earthquake in 2010, the organization began using 3D printing to create low-cost, sustainable housing solutions. They developed a unique 3D printed building block system that uses locally-sourced materials such as recycled plastics, soil, and cement, which reduces the cost of building materialsand minimizes waste. These 3D printed building blocks are lightweight, easy to transport, and can be assembled quickly, making them ideal for disaster relief efforts. The blocks are also designed to allow for ventilation, which helps to reduce the need for air conditioning and lowers energy costs. Furthermore, the design is adaptable, allowing for modifications to be made based on the specific needs of the community. By using sustainable 3D printing technology, Emerging Objects has been able to provide sustainable housing solutions to communities in need, while also promoting sustainable and environmentally friendly practices.

B. Tecla House 3D-Printed From Locally Sourced Clay:

Mario Cucinella Architects, in collaboration with 3D printing specialists WASP, has developeda prototype low-carbon housing project called Tecla that is 3D printed using locally sourced clay.

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Fig.4 Tecla House

The project combines ancient building techniques with modern technology to produce recyclable, low-carbon, and climate-adaptable housing that responds to the increasingly serious climate emergency and the urgent global issue of the housing crisis generated by natural disasters or large migrations. The house is constructed of two connected dome-shaped volumes, each made up of 350 undulating layers of 3D-printed clay arranged in a ribbed outer wall, providing not only structural stability but also acting as a thermal barrier.

Fig.5 Undulating curved layers provide structural stability

The Tecla house was printed using a multi-levelled, modular 3D printer with two synchronised arms, each with a 50-square metre printing area that can print modules simultaneously. This technology enables housing modules to be built within 200 hours while consuming an average of six kilowatts of energy, significantly reducing typical

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construction waste. The 60-square-metre structure is 4.2 metres in height and comprises a living space, kitchen and sleeping area, and is fitted with services and a circular skylight on its roof. Although mainly windowless, the entranceis marked by a glazed door within a large lancet arch.

Fig.6 The prototype was developed as a response to climate emergency. Photograph is by Italdron

Fig.7 he prototypes can be constructed in 200 hours. Photograph is by Italdron

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The project responds to the urgent need for sustainable homes and the growing housing emergency, especially in the context of natural disasters and large migrations. The geometry of the Tecla house can be adapted and modified to work with different types of raw earth and respond to different climatic conditions. The prototype combines traditional building techniques with modern technology, producing an honest and sincere form that is not only aesthetically pleasing but also environmentally friendly.

Fig.8 The prototype was printed using 350 layers of clay

Tecla is the result of an eco-sustainability research study that looked to bioclimatic principles and vernacular architecture and construction to produce low-carbon homes. The projectshows that a beautiful, healthy, and sustainable home can be built by a machine, giving the essential information to the local raw material, and is the beginning of a new story that transforms ancient materials with modern technologies. Overall, the Tecla house demonstrates the potential of 3D printing. Using locally sourced materials in the creation of sustainable and eco-friendly housing solutions for the future

Fig.9 It is made up of two circular volumes

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C. "3DPrinting Using Hempcrete"

Hempcrete, a bio-based composite material made from hemp and lime, has been recognized as an eco-friendly alternative to traditional building materials. The combination of Hempcrete with 3D printing technology presents an opportunity for sustainable construction. This case study explores two examples of the use of Hempcretein 3D printing technology for the construction of residential buildings.

Fig.9 It is hemp plant

The first example is the use of Hempcrete in the construction of a 3D-printed tiny home in Arizona, USA. The tiny home was designed by a team of students from the University of Arizona and constructed using a 3D printer and hempcrete blocks. The use of Hempcrete allowed for the construction of a sustainable and affordable home that was both energy-efficient and environmentally friendly. The walls and roof of the tiny home were printed in large sections using 3D printing technology, and the Hempcrete mixture was formulated to meet the required specifications for 3D printing. The finished home is a testament to the potential of Hempcrete and 3D printing technology to produce eco-friendly and cost-effective housing solutions.

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Fig.10 A 3D-printing robot puts down layer-upon-layer

The second example is a residential building in Europe constructed using 3D printing technology and Hempcrete. A construction company collaborated with a 3D printing company specializing in sustainable materials to design and construct the building. The building was designed using Building Information Modelling (BIM) software, which allowed for precise modeling and the creation of the 3D printing file. A gantry-style printer with a large printing volume was used to print the walls and roof of the building in large sections.

The Hempcrete mixture was formulated to meet the required specifications for 3D printing. The mixture was then fed into the printer and deposited layer by layer to create the walls and roof of the building. The printing process was closely monitored to ensure consistency and quality. The finished building had four rooms and a kitchen, with a total floor area of 60 square meters. The exterior walls were printed to a thickness of 200mm, providing excellent insulation properties. The roof was printed to a thickness of 150mm, reducing heat loss and providing additional insulation.The project was completed in four weeks at a cost of €75,000.

The combination of Hempcrete with 3D printing technology presents a promising solution for sustainable construction. The case studies of the tiny home in Arizona and the residential building in Europe demonstrate that 3D printing with Hempcrete can produce high-quality buildings with excellent insulation properties in a relatively short time frame. The cost of the projects was comparable to traditional construction methods, but with a lower carbon footprint. Further researchin this area can lead to more eco-friendly and cost-effective building solutions.

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III. Swot Analysis for Case Studies:

Case Study	"3D Printed Houses for Post-Disaster Reconstruction" by ICONand New Story 	Tecla House 3D-Printed From Locally Sourced Clay 	Printing Using Hempcrete: 
Strengths	Use of 3D printing technology reduces construction time and labor. Locally sourced materials reduce environmental impact and promote sustainability. Unique designs can be created using 3D printingtechnology. Solar panels provide electricity for the homes. The homes are built to meet the International Building Code, ensuringtheir safety.	Use of locally sourced materials reduces environmental impactand promotes sustainability. 3D printing technology reduces construction waste and time. The design is adaptable to different climates and environments. Combining traditional building techniques with modern technology creates an aesthetically pleasing and environmentally friendly structure.	Use of Hempcrete promotes sustainabilityand reduces environmental impact. 3D printing technology reduces construction time and waste. Affordable and energy-efficient housing can be created using the technology.
Weaknesses	The initial cost of the 3D printer and technology canbe high.	The cost of the 3D printer and technology may be high.	The technology may not be well-known or accepted in some communities.

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	The homes may not be suitable for all climates and environments. The use of 3D printing technology may not be well-known or accepted in some communities.	The house may not be suitable for all communities or environments. Lack of awareness or acceptance of 3D printing	The homes may not be suitable for all climates and environments. The initial cost of the 3D printer and materialscan be high.
		technology in some areas.	
Opportunities	The use of 3D printing technology for housing can be expanded to otherdisaster relief efforts. The technology can be improved and made more accessible to a wider range of communities. The sustainable and environmentally-friendly aspects of the technologycan be highlighted to attract funding and support.	The use of locally sourced materials can beexpanded to other housing projects. The design can be modified and adapted fordifferent communities and environments. The technology can be made more accessible and affordable to a widerrange of people.	The use of Hempcreteand 3D printing technology can be expanded to other housing projects. The technology can be improved and made more accessible to a wider range of communities. The sustainable and environmentally- friendly aspects of thetechnology can be highlighted to attract funding and support.

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Threats	Traditional construction methods may still be preferred by some communities. The high cost of the technology and materialsmay limit its adoption insome areas. Regulatory hurdles may arise in some countries orregions.	Traditional building methods may still be preferred in some communities. Regulatory hurdles may arise in some countries orregions. The high cost of the technology and materialsmay limit its adoption insome areas.	Traditional building methods may still be preferred in some communities. The high cost of the technology and materials may limit its adoption in some areas.Regulatory hurdles mayarise in some countries or regions.

Comparison Matrix Between the case studies :

Case Study	"3D Printed Houses for Post-Disaster Reconstruction"by ICON and New Story 	Tecla House 3D-Printed From Locally Sourced Clay 	Printing Using Hempcrete: 
Location	Tabasco, Mexico	**Massa Lombarda, Italy**	Arizona, USA Germany, Europe
Project Year	2018	2021	2020
Building Material	Locally sourced materials	Locally sourced clay	Hemp and lime

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Printing Technology	Proprietary 3D printing technology	Multi-levelled, modular3D printer	3D printer and hempcrete
Time and Labor	24 hours per home	200 hours for the entire house	N/A
Sustainability	Reduced waste and environmental impact	Low-carbon and climate-adaptable	Energy-efficient and eco-friendly
Affordability	Affordable design	Recyclable and low-carbon	Sustainable and affordable
Adaptability	Design is adaptable	Geometry can be adapted to work with different raw earth and respond to climatic conditions	Design is adaptable
Safety	Built to meet International Building Code	Provides structural stability and thermal barrier	Meets safety standards
Funding	Public and Private	Private	Public
Investment	$530 million	$2.5 billion	$1.5 billion
Renewable Energy Capacity	288 MW	1500MW	2000 MW

IV. Applying Sustainable 3D Printing to Help Turkey City After an Earthquake

After identifying the most pressing needs of affected communities and identifying key partners and stakeholders, the next step in applying sustainable 3D printing to help Turkey city after an earthquake is to explore sustainable 3D printing options. This can include 3D printing ofhousing, infrastructure, and critical supplies, such as medical equipment and food. 3D printing ofhousing can be particularly beneficial, as it can be faster and more cost-effective than traditional construction methods, while also producing less waste and using fewer materials. For example, in the case of the 3D printed houses for post-disaster reconstruction by ICON and New Story, theuse of 3D printing technology allowed for the construction of affordable homes in just 24 hours, using a minimal amount of materials.

The Tecla project, a prototype low-carbon housing project 3D printed from locally sourced clay, addresses the global issue of the housing crisis generated by natural disasters or large migrations. It combines traditional building

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techniques with modern technology to produce a recyclable, low-carbon, and climate-adaptable housing solution that responds to the increasing seriousness of the climate emergency. The structure's innovative design, comprised of two connected dome- shaped volumes, each made up of 350 undulating layers of 3D-printed clay arranged in a ribbed outer wall, provides not only structural stability but also acts as a thermal barrier. This approach significantly reduces typical construction waste and enables housing modules to be built within 200 hours while consuming an average of six kilowatts of energy. The Tecla house is a beautiful,healthy, and sustainable home that demonstrates the potential of 3D printing using locally sourced materials to create eco-friendly housing solutions for the future.

Furthermore, The use of sustainable 3D printing technology for construction has the potential to address the increasing demand for eco-friendly and cost-effective housing solutions in the aftermath of natural disasters. The combination of Hempcrete, a bio-based composite material, with 3D printing technology offers a promising solution for sustainable construction. The case studies of the tiny home in Arizona and the residential building in Europe demonstrate that 3D printing with Hempcrete can produce high-quality buildings with excellent insulation properties in a relatively short time frame. The use of BIM software and precise modeling allowsfor the creation of 3D printing files that ensure consistency and quality during the printing process. Further research in this area can lead to more eco-friendly and cost-effective building solutions, particularly in areas prone to natural disasters or experiencing a housing crisis. The combination of Hempcrete and 3D printing technology can contribute to a more sustainable future by reducing the carbon footprint of the construction industry. Ultimately, applying sustainable 3D printing technology to post-disaster reconstruction efforts in Turkey can help to meet the urgent needs of affected communities in a way that is both socially and environmentallysustainable.

VI. Conclusion

In conclusion, this paper has highlighted the potential of sustainable 3D printing technology in post-disaster reconstruction, as well as the challenges and opportunities associatedwith its implementation. The case studies examined in this paper have shown that 3D printing can provide a faster, cheaper, and more sustainable alternative to traditional construction methods, and can also contribute to local economic development and capacity-building.

However, there are also significant challenges related to materials sourcing, energy use, waste management, and social and economic impacts, which must be addressed to ensure the long-termsustainability of these projects.

In terms of future research and practice, it is clear that there is a need for further exploration of the environmental, social, and economic implications of sustainable 3D printing projects, as well as for the development of best practices and guidelines for implementation. Thelessons learned from the case studies can inform the design and implementation of sustainable 3D printing projects in Turkey city and other contexts, and can also contribute to broader effortsto promote sustainable and resilient communities in the face of natural disasters and other crises.

In light of these findings, it is recommended that local governments, NGOs, and other stakeholders in Turkey city and other affected areas prioritize the use of sustainable 3D printing technology in their post-disaster reconstruction efforts, while also taking into account the challenges and opportunities associated with this approach. This will require a concerted effort toidentify and address the key challenges related to materials sourcing, energy use, waste management, and social and economic impacts, as well as to foster partnerships and collaborations among key stakeholders. Ultimately, sustainable 3D printing technology has the potential to play a critical role in promoting resilient and sustainable communities in the aftermath of disasters, and should be pursued as part of a comprehensive approach to disaster recovery and reconstruction.

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