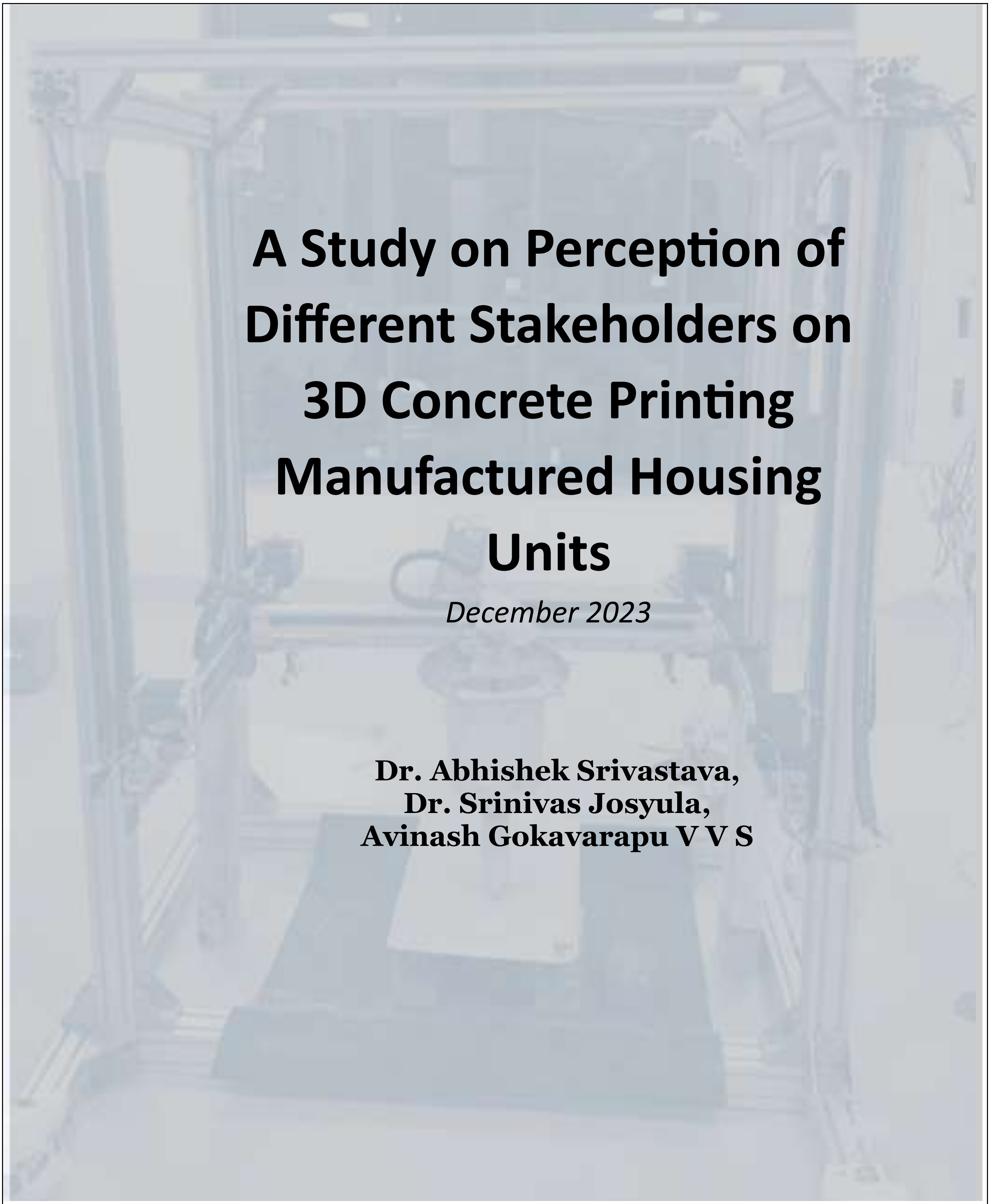

A Study on Perception of Different Stakeholders on 3D Concrete Printing Manufactured Housing Units

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CAD	Computer-aided Design
CC	Contour Crafting
3DCP	3D Concrete Printing
C3DP	Construction 3D Printing
3DP	3D Printing
MoHUA	Ministry of Housing and Urban Affairs
PMAY-U	Pradhan Mantri Awas Yojana-Urban
BLC	Beneficiary Led Construction
AHP	Affordable Housing in Partnership
ISSR	In-situ Slum Redevelopment
CLSS	Credit Linked Subsidy Scheme
GHTC	Global Housing Technology Challenge

Executive Summary

Housing is a pivotal element of human development, intricately linked with global Sustainable Development Goals (SDGs). A 2017 McKinsey Report indicates that approximately 330 million urban households globally face housing challenges, which are projected to rise to 440 million by 2025. In India, the housing sector grapples with challenges such as population growth, slum proliferation, and constrained urban services. Urban India, as of the 2011 census, recorded 0.9 million homeless individuals and 65 million people in slums.

The Indian government, recognizing the housing imperative, initiated policies in the 1950s, evolving from welfare-centric to economically oriented. Since June 2015, the Pradhan Mantri Awas Yojana-Urban (PMAY-U) has been a flagship program to provide all-weather houses in urban areas. The program adopts a cafeteria approach, considering geographical and economic conditions.

Technology plays a pivotal role, with the Technology Sub-Mission (TSM) promoting sustainable and efficient construction methods under PMAY-U. The Global Housing Technology Challenge-India (GHTC-India) aims to mainstream innovative global construction technologies, fostering an ecosystem of research and development.

The real estate sector, vital for economic growth, has seen recovery post-pandemic, driven by increased demand for home ownership. The government's interventions, like PMAY-CLSS, RERA, and GST, have bolstered the sector, leading to double-digit growth in construction.

The adoption of Proptech (property technology) is revolutionizing real estate, integrating cloud computing, AI, and IoT for enhanced efficiency. Additionally, 3D concrete printing technology is poised to transform construction, offering design freedom, reduced waste, and faster construction times.

As India embraces the future, the integration of 3D concrete printing technology is a revolutionary disruption in the construction sector. This innovative approach promises design flexibility, minimized waste, faster construction, sustainability, and cost-effectiveness. The housing sector, thus, continues to evolve with technology, innovation, and government initiatives, driving inclusive and sustainable solutions while also propelling economic growth.

As part pf this research a 3D concrete printer prototype was also created to demonstrate a Proof of Concept (POC) in a tangible and interactive manner and to bring out the challenges encountered during this intricate process.

The stakeholder analysis of 3D concrete printing technology for housing construction in India reveals a wide range of perceptions and attitudes towards the technology. The study analyzed the perceptions of four key stakeholders: Consumers, builders, contractors in the housing sector, bankers and financial institutions, academia, and researchers.

Based on the existing literature and the analysis of stakeholders' perceptions, the following key recommendations are put forth. To seamlessly integrate 3D concrete printing (3DCP) into mainstream housing construction, it is imperative to address existing knowledge gaps among stakeholders. Proposing the establishment of Centers of Excellence in a public-private partnership (PPP) model, primarily focusing on research, knowledge dissemination, sustainability practices, and building material for 3DCP. Advocating for government publication of regulations, quality standards, and guidelines for 3DCP in the housing sector is crucial to fostering trust, mitigating safety risks, and minimizing barriers to adoption. Encouraging adoption can be facilitated through financial incentives, subsidies, and accessible loans. Government funding and sponsorship are essential for model projects that showcase the effectiveness of 3DCP. To reduce skill gaps, emphasis should be placed on academic courses, workforce training programs, and targeted skilling initiatives, ensuring a smooth transition to 3DCP in the housing sector while mitigating resistance and safeguarding the livelihoods of impacted workers. Promoting eco-friendly practices is pivotal to making 3D-printed housing accessible and affordable, effectively addressing consumer concerns. Additionally, conducting longitudinal studies is recommended to assess the long-term viability of 3DCP in the Indian context.

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Chapter 1: Introduction

Housing is an essential and integral element of human development and well-being and intersects significantly with the global commitment to achieve the Sustainable Development Goals (SDGs).

As per the McKinsey Report (Mckinsey, February 2017), globally, 330 million urban households with low to moderate incomes either reside in inadequate housing or face significant financial strain due to housing expenses, leading them to prioritize necessities like healthcare and education. By the year 2025, this number is projected to escalate to 440 million households, affecting approximately 1.6 billion individuals, which is equivalent to one-third of the world's urban population. It's crucial to note that this estimation does not encompass some of the most impoverished individuals who often live outside urban areas, on city streets, or as squatters, rendering them unaccounted for in census assessments.

The housing sector in India is a critical facet of the country's developmental narrative, reflecting the dynamic interplay between urbanization, demographic shifts, and economic growth. Today, India grapples with a host of challenges, ranging from population growth, evolving family structures, shifting family dynamics, a surge in slum settlements, constrained urban services, and climate change concerns to heightened migration. These issues have resulted in a housing backlog, an infrastructure deficit, and the proliferation of informal settlements.

According to 2011 census data, urban India had 0.9 million homeless individuals, and approximately 65 million people resided in slums, constituting 17% of the urban population. The critical role of housing is underscored by the migration from rural to urban areas in search of livelihood, housing shortages, and the expansion of informal settlements, influencing both government policies and private investments. As India aims to become a global economic force, the government faces unprecedented challenges in providing sufficient and affordable housing. Balancing urban growth with environmental sustainability, addressing housing shortages for economically marginalized segments, and navigating regulatory intricacies are among the multifaceted challenges. These complexities highlight the critical role of housing as a primary driver of economic growth, impacting various sectors, including raw material demand in the primary sector, construction material needs in the manufacturing sector, and contributions to the service sector involving professionals, skilled labour, and financial institutions and Insurance sector. These contemporary challenges underscore the complexity that the government faces as it endeavours to establish holistic housing solutions that are both inclusive and sustainable.

India initiated housing policies in the early 1950s during the commencement of 'planned development.' In the initial years, these policies were primarily welfare-oriented. However, over time, they evolved to incorporate economic considerations. Simultaneously, the government's role shifted from being a provider of housing to that of a facilitator.

Since June 2015, the Government of India, under the Ministry of Housing and Urban Affairs (MoHUA), has been executing the Pradhan Mantri Awas Yojana-Urban (PMAY-U), a key flagship program. This initiative aims to provide all-weather, permanent houses to eligible beneficiaries in the urban areas of the country. The program encompasses the entire urban area of India, including all statutory towns as per Census 2011 and towns notified subsequently, along with Notified Planning/Development Areas. PMAY-U operates through four verticals: Beneficiary Led Construction/Enhancement (BLC), Affordable Housing in Partnership (AHP), In-situ Slum Redevelopment (ISSR), and Credit Linked Subsidy Scheme (CLSS). All the houses under PMAY-U have basic amenities like toilets, water supply, electricity, and a kitchen. The Mission promotes women's empowerment by providing the ownership of dwellings in the name of the female members or in a joint name. Preference has also been given to differently-abled persons, senior citizens, SCs, STs, OBCs, Minorities, single women, transgender and other weaker and vulnerable sections of society.

A PMAY-U house ensures dignified living along with a sense of security and pride of ownership to the beneficiaries. PMAY-U has adopted a cafeteria approach to suit the needs of individuals based on geographical conditions, topography, economic conditions, availability of land, infrastructure, etc.

As part of PMAY-U, MoHUA has established a Technology Sub-Mission (TSM) with the mission of "***Sustainable Technological Solutions for Faster and Cost-Effective Construction of Houses suiting Geo-Climatic and Hazard Conditions of the Country***." This initiative promotes the use of modern, innovative, and green technologies, as well as building materials, to expedite and enhance the quality of house construction. The Technology Sub-Mission (TSM) also aids in developing layout designs and building plans tailored to different geo-climatic zones, while assisting states and cities in implementing disaster-resistant and environmentally friendly technologies. A total of 33 alternate technologies have been identified, and approximately 15 lakh houses are currently under construction nationwide using these innovative approaches. (Pmay, n.d.)

Further, MoHUA has initiated the **Global Housing Technology Challenge - India** (GHTC-India), which aims to identify and mainstream a basket of innovative construction technologies from across the globe for the housing construction sector that is sustainable, eco-friendly, and disaster-resilient. They are to be cost-effective and speedier while enabling the quality construction of houses, meeting diverse geo-climatic conditions and desired functional needs. Future technologies will also be supported to foster an environment of research and development in the country. GHTC- India aspires to develop an ecosystem to address the technological challenges of the housing construction sector in a holistic manner.

Hon'ble Prime Minister of India inaugurated the Construction Technology India- 2019, a global Expo-cum-Conference, which was organized on 2-3 March 2019 in New Delhi. 60 Exhibitors with 54 proven technologies from 25 countries showcased their technologies at the Expo. Prime Minister declared the year 2019-20 as the ***'Construction Technology Year'***.

Under Affordable Sustainable Housing Accelerators - India (ASHA-India) initiative, incubation, and acceleration support are provided to potential future technologies that are not yet market-ready (pre-prototype applicants) or to the technologies that are market-ready (post-prototype applicants). The ASHA-India Centres were to be set up to help in developing design guidelines, construction manuals, and other necessary guidelines relevant to the effective use of such technologies in the region. ASHA-India Centres were planned to be set up at five host institutions: IIT Bombay, IIT Kharagpur, IIT Madras, IIT Roorkee and CSIR-NEIST, Jorhat. And 72 potential future technologies (domestic) have been identified through the challenge, which will be shortlisted for providing support under ASHA-India. (Jonathan Woetzel, 2014)

1.1 Light House projects under GHTC India

The Light House projects (LHPs), to be developed under GHTC India, will serve as live laboratories for different aspects of the transfer of technology to the field. This includes planning, design, production of components, construction practices, and testing for faculty and students of IITs/ NITs/ Engineering colleges/ Planning and Architecture colleges, builders, professionals of private and public sectors, and other relevant stakeholders. GHTC India ushered a paradigm shift in construction technology to transform the eco-system of housing construction.

For the use of innovative technology in construction, the Ministry has introduced a Technology Innovation Grant as an additional grant of Rs. 4.0 Lakh per house over and above the existing share of Rs 1.5 lakh per house under PMAY(U) for LHPs. The LHPs are being implemented in Gujarat, Jharkhand, Madhya Pradesh, Tamil Nadu, Tripura, and Uttar Pradesh to demonstrate innovative construction technologies that are cost-effective, green, and sustainable.

To support this sunrise sector, the Government of India, in the Union Budget 2023-24, announced a commitment of Rs. 79,000 crore (US$ 9.64 billion) for PM Awas Yojana has been announced, which represents a 66% increase compared to the previous year. Thnjhm.,/;' e enhanced allocation for PM Awaas Yojana by 66% to over INR 79,000 crore is undoubtedly a boost for affordable housing, which was flagging due to increased input costs and because the buyers in this segment, mainly from the unorganized sector, were still reeling under the impact of the pandemic.

1.2 Real Estate and Construction Sector in India

The real estate sector is one of the most globally recognized sectors. It comprises four sub-sectors - housing, retail, hospitality, and commercial. The growth of this sector is well complemented by the growth in the corporate environment and the demand for office space as well as urban and semi-urban accommodation. The construction industry ranks third among the 14 major sectors in terms of direct, indirect, and induced effects in all sectors of the economy.

In India, the real estate sector is the second-highest employment generator after the agriculture sector. As the global economy gradually recovers from the pandemic, sales volumes in the real estate sector experience a paradigm shift as the end users, due to the uncertainty caused by the pandemic, start gravitating towards the security of home ownership. Ownership of a home does provide a strong sense of stability. The increase in sales was facilitated by historically low interest rates on home loans, steady house prices, and demand-boosting initiatives implemented by certain State Governments. Remarkably, even after the initial demand surge prompted by these incentives, the momentum in sales persisted without the need for additional support. The construction sector in India grew in double digits at 10.4 percent during the fourth quarter of 2022-23 due to sustained impetus on infrastructure spending by the Indian Government. (htt1)

According to the NHB Annual Report (Report, 2022-23) The real estate sector has undergone a comprehensive recovery following two extended years of pandemic-related lockdowns and ensuing economic challenges. The aspiration for homeownership has intensified since the onset of the pandemic and continues to hold strong. Pandemic-driven trends, such as remote and hybrid working, have led homebuyers to seek more significant, sustainable spaces with added-value services and amenities that enhance overall well-being. This shift in buying preferences draws customers toward peripheral areas close to city centers. Additionally, factors like rapid urbanization, increasing income levels, the rise of nuclear families, the entry of new real estate developers, and the availability of financial options for both developers and homebuyers have contributed to the growth of the real estate sector.

Since 2015, the housing sector exhibited a paradigm shift as demand and supply side interventions by the Government, viz. launching of mission "***Housing for All***," with a target of 11 million houses in Urban and 29.5 million houses in Rural India, interest subvention under PMAY-CLSS, implementation of RERA(Real Estate Regulatory Authority) and GST (Goods and Services Tax), infrastructure status to affordable housing, tax benefits for both home buyer and seller etc. have started paying out in providing the much-needed protection to homebuyers and provided greater impetus to growth of housing sector in India.

Housing Finance Companies have become vital intermediaries in India's financial system, playing a crucial role in extending financial assistance to the housing segment. During the FY 2022-23 year, the individual housing loan disbursement by housing finance companies, public sector banks, and private sector banks grew by 19.88 percent (y-o-y). The series of initiatives and interventions taken by the Government of India, Reserve Bank of India, and NHB over the years supported the housing finance institutions to steer through the pandemic undeterred.
According to IBEF (Improved affordability pushes home sales in India to a new peak in 2023, 2023), the affordability of homes in India has shown a positive trend compared to the the preceding year, as evidenced by the notable increase in sales figures.

According to recently published reports, the affordability index, which is the ratio of equated monthly installments to income, witnessed improvement across the country. Sales in the top seven cities reached an unprecedented high, totaling 476,530 units, marking a substantial 31% increase from the 364,870 units recorded in 2022. The Individual Housing Loan disbursement by Housing Finance Companies (HFCs) showed a consistent increase from ₹1.89 lakh crore in FY20 to ₹1.91 lakh crore in FY21, ₹2.61 lakh crore in FY22 and ₹3.11 lakh crore in FY23.
According to Crisil, Housing sales are expected to grow by 11-13 percent in 2023-24. The rating agency expects the increase in sales to be driven by higher consumer demand and stable interest rates during this period. The demand for houses in the top 8 cities is likely to grow by 6-9 percent over the next two years.

1.3 Technology Adoption in the Construction Sector

As technology rapidly progresses, the construction and housing sectors are quickly integrating emerging digital technologies. To maintain competitiveness, construction businesses are compelled to adopt diverse technology trends, thereby transforming operations, improving efficiency, and reducing costs. Despite being the largest component of the global economy, valued at around USD 196 billion, according to Statista, the real estate industry initially lagged in embracing digitalization. Nevertheless, it is now actively bridging this gap by adopting the latest trends in real estate technology.

Proptech, a fusion of "property" and "technology," amalgamates housing/ real estate technologies like cloud computing, mobile solutions, artificial intelligence, and the Internet of Things (IoT) to provide advanced solutions for the housing industry. Proptech solutions aim to revolutionize the way people buy, sell, rent, and manage their housing estates. These solutions encompass temperature control for smart homes, smart lighting, security systems, data-driven property management, automated business processes, and virtual property tours. Proptech empowers housing/ real estate businesses to enhance efficiency, improve service quality, and reduce costs, gaining widespread popularity for its transformative potential in the industry. Proptech is gaining immense popularity because of its potential to revolutionize the Housing/ construction industry.

1.4 3D Printing: The Future of the Construction Industry

Today, the construction industry stands on the brink of a technological revolution with 3D printing technology. This technological disruption, poised to redefine traditional building methods through 3D printing technology, is also known as additive manufacturing. This innovative technology transforms the design and construction of our built environment, unlocking limitless architectural possibilities.

The 3D printing process in the construction of a house begins with creating a digital model using specialized CAD software, serving as the blueprint for the printer. The digital model undergoes conversion into a format compatible with the specific 3D printing technology. Material selection follows, commonly using durable and affordable concrete, with potential exploration of other materials like polymers and recycled materials. (Suhas Ramachandra, 2023)

During printing, the 3D printer deposits layers of material based on the digital blueprint, offering unprecedented design freedom and reducing construction time. This layer-by-layer approach ensures precise control over material distribution and structural integrity, resulting in efficient and robust structures. Proper curing methods, such as chemical reactions or heat application, maintain the strength of the printed components.

Post-processing steps may include removing support structures, smoothing surfaces, and integrating traditional construction elements. The benefits of 3D printing in construction encompass design freedom, reduced material waste, shorter construction times, sustainability, and cost-effectiveness, ushering in a transformative era for the industry.

1.5 Motivation

Over the past decade, the construction sector has witnessed stagnant productivity, lagging in the adoption of the latest technologies, particularly Industry 4.0. Despite constituting 13% of the world GDP with global spending of $10 trillion, the construction sector's labour productivity growth has averaged only 1% annually in the last 20 years, contrasting sharply with the 2.8% of the world economy and 3.6% in the manufacturing sector (Mckinsey, February 2017). The low productivity in the construction sector was attributed to underinvestment in digitization and innovation.

Against the backdrop of substantial housing demand in developing contexts like India, coupled with governmental initiatives like "Housing for All," this study explores the opportunities for the adoption of the transformative potential of emerging technologies, particularly 3D concrete printing (3DCP), to enhance productivity and efficiency in the construction sector. Recognizing the nascent stage of 3DCP globally, the study emphasizes its pioneering role in additive construction for housing projects in the Indian context.

This study attempts to understand the perception of stakeholders in housing sector regarding their awareness and knowledge, perceived benefits and challenges, market adoption and Barriers, stakeholders' involvement and skill needs, Quality, Sustainability and future outlook on 3DCP built housing.

Further, this study also designs and develops a 3DCP prototype for stakeholder demonstration.

1.6 Study Objectives

Based on the outlined motivation, this study has come up with the following four objectives.

1. Study of the evolution of 3DCP.
2. Design and develop a 3 DCP prototype.
3. Stakeholder's Perception and Analysis.
4. Provide Recommendations to improve the adoption of 3DCP technology and alleviate some of the perceptions amongst stakeholders.

1.7 Report Overview

This Report is divided into five chapters.

Chapter 1: It outlines the critical role of housing in both economic and human development, addressing evolving societal needs, global challenges, and the hurdles faced by governments in ensuring adequate and affordable housing. It delves into various initiatives by the Government of India, key policy interventions, and the flagship scheme PMAY, along with other sub-missions like the Technology Sub-Mission by the Ministry of Housing and Urban Affairs (MoHUA). Additionally, the chapter explores the Global Housing Technology Challenges, aimed to mainstream innovative construction technologies, and sheds light on Light House Projects under the GHTC scheme. The discussion extends to the Real Estate and Construction Sector in India, the adoption of technology in the construction and housing sectors, and the emergence of 3D printing as a disruptive, transformative force in the construction industry. The chapter also covers the motivation behind the study and the study objectives and chapterisation.

Chapter 2: This section presents an in-depth exploration of 3D Concrete Printing (3DCP) technology, delving into its evolution as documented in existing literature. It comprehensively examines the advantages and obstacles associated with 3DCP, offering a nuanced understanding of the technology's intricacies. Following this analysis, the chapter further elucidates the present state of 3DCP in the context of India, shedding light on the current advancements and initiatives in the country.

Chapter 3: This chapter showcases the technical intricacies, elucidating various stages involved in the creation and enhancement of a 3D Concrete Printing (3DCP) prototype. This prototype assumes a pivotal role as it transforms into an indispensable tool for presenting a tangible Proof of Concept (POC) in a dynamic and interactive manner. It also transparently articulates the challenges encountered within this intricate process of designing and development.

Chapter 4: This chapter presents the core of our inquiry, focusing on the examination of stakeholder perceptions. Within this chapter, we present the analysis of data gathered from four distinct stakeholder groups: builders and professionals in the construction sector, banks and financial institutions, academics and researchers, and consumers. The analysis scrutinizes stakeholders' perspectives on various aspects, including Knowledge and Awareness regarding 3D Concrete Printed houses, Perceived Benefits, Perceived Challenges, Quality and Durability, Stakeholder Involvement & Skilling Needs, Market Adoption, Acceptance & Barriers, and Future Outlook.

Chapter 5: This chapter consolidates the findings and, drawing from these insights, offers a set of recommendations aimed at enhancing the adoption of 3D Concrete Printing (3DCP) technology and mitigating certain perceptions among stakeholders.

Chapter 2: Evolution of 3DCP

2.1 Overview

Construction Industry is one of the largest industries in the world. (Gerbert P, 2021). Construction companies are looking for ways to increase productivity. (Maskuriy R, 2019) Labor productivity was increasing, but as per some studies, it has been found that a lack of knowledge about new technology is resulting in a downfall in labour productivity. (T., 2015) . Not only lack of knowledge but lack of implementation of this technology is also a reason for the downfall. (García de Soto B, 2018).

3D printing technology is under good attention in the housing industry as a replacement strategic challenge. The development industry takes 3D printing as a concept of a replacement building technology. (Prachi Mehar*, 2020)

Dictionary.com defines 3D printing as *"a printing process that involves making three-dimensional objects from digital models by applying many thin layers of a quick-drying material on top of each other"* (Random House Inc, 2023).

According to Bogue, 3-D printing is an automated, additive manufacturing process for producing 3-D solid objects from a digital (i.e., CAD) model (Bogue, 2013).

According to Berman, 3-D printing employs an additive manufacturing process whereby products are built on a layer-by-layer basis through a series of cross-sectional slices (Berman, 2012). The term 3-D printing can also be applied to office or consumer versions of rapid prototyping machines that are relatively low-cost and easy to use (Casey, 2009).

Printing of concrete using a 3D concrete printer (3DCP) is an evolving technology that has the potential to revolutionize the construction industry (Das, 2022). Additive manufacturing (AM), also known as 3D printing, is one of the newest technologies in the block; if this technology is implemented in the construction industry, then the construction industry can be revolutionized. (Brettel M, 2014) (Oesterreich TD, 2016). 3D printing can be used to print anything that is sketched in 3D (S. Manjikian, 2020). The main advantage of AM is its ability to produce parts from a CAD model, which saves time and cost, mainly for prototypes. (Gibson I, 2015).3D printing helps address sustainability issues (Gebler, 2014).

The construction industry has been recognized as one industry that consumes a considerable number of resources and poses significant environmental stresses (Wu P, 2016) . With the development of technology, some economic and environmental issues have emerged. (R. He, 2021) . For example, construction has a bad effect on the environment, and there is always a risk of uncertain prices and price rises in the construction and related sectors, which leads to the adoption of a more sustainable method of construction like 3D Printing. In the case of 3D Printing, we should not only look at the sustainable, cost-effective, and technically advanced aspects of 3D Printing but should equally stress the non-technical aspects like environmental friendliness. (Xin Ning, 2021).

In 2022, the revenue of the worldwide 3D concrete printing market stood at USD 210 million. Forecasts predict substantial growth, with an anticipated value of USD 9095.18 million by 2031, reflecting a remarkable compound annual growth rate (CAGR) of 52% over the forecast period from 2023 to 2031 (Straits Research, 2023).

2.2 3D Printing in Construction Industry

Earlier, the application of 3D printing was restricted only to the manufacturing sector (Berman, 2012). Charles Hull, known as the father of 3D Printing, developed the first commercial 3D Printing machine. (M. H. Ali, 2019), he used the stereolithography method of 3D printing. (Peng Wu1, 2016).

The first ever 3D printing efforts were made by Dr. Hideo Kadoma, who developed a rapid prototyping technique in 1981. He developed a system that printed solid layers of fast-drying photopolymers, which resembled a cross-section slice of a CAD model. (P. Wu J. W., 2016).

Experimental applications using 3D printing in the construction industry started in the early 1990s (Camacho D, 2018). The first attempt at using 3D printing in the construction industry was made in 1995 by Dr. Behrokh Khoshnevis. He used stereolithography to produce three-dimensional ceramic parts. However, the mechanical properties of the parts were not optimized. (C. Hinczewski, 1998)

In 2001, Dr. Khoshnevis printed a wall using an FDM 3D printer that is mounted on a robotic arm to extrude concrete layers. Dr. Khoshnevis called this new technology Contour Crafting (CC). Contour Crafting can be defined as “an additive fabrication technology that uses computer control to exploit the superior surface-forming capability of troweling to create smooth and accurate planar and free-form surfaces out of extruded materials” (J. Zhang, 2011).

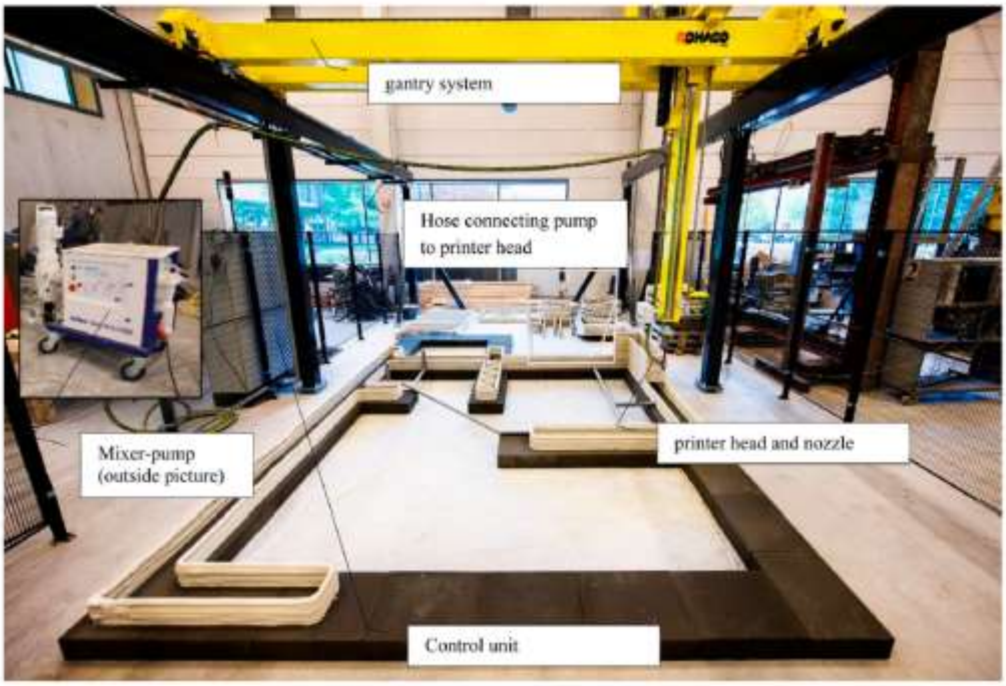

Figure 2.1 Parts of 3DCP (image credit 3DCP facility at the TU Eindhoven)

There are primarily five 3D printing processes: Stereolithography, Fused Deposition Modeling (FDM), Inkjet Powder Printing Process, Selective Laser Sintering (SLS), and Contour Crafting. The construction industry specifically employs Contour Crafting, the latest type of 3D printing. The CC technology demonstrated all the qualities needed to use additive manufacturing on construction sites: reduction in costs, materials waste and accidents, faster construction speed, complex architectural shapes, and more. (S. Lim, 2012)

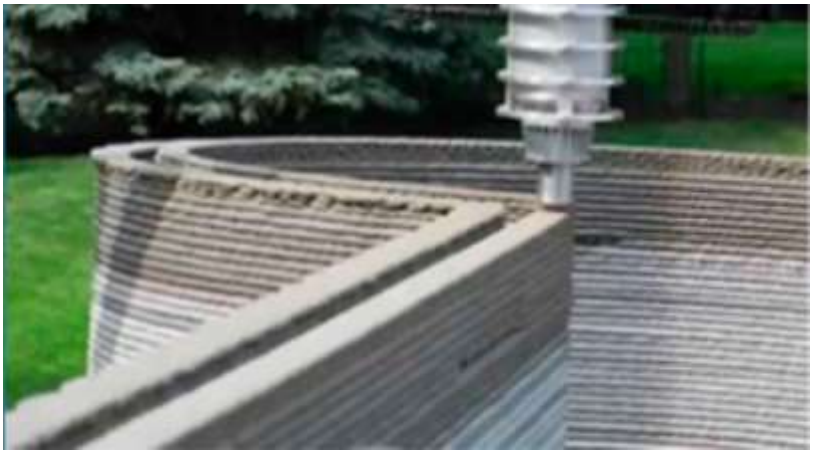

Figure 2.2 Showing 3DCP technique.

Apart from Contour Crafting, there are other types of printing available for the construction industry; for example, the research team at Loughborough University has developed a concrete printing process (which is referred to as Concrete Printing). A process called D-shape has also been developed by straining a binder on the material layer. 3D printing enables faster construction without compromising on mass customization (Barlow, 2003).

Two main scenarios can be considered for widespread adoption of C3DP technology by the construction industry: (1) Using concrete 3D printers in the prefabrication facilities to produce structural elements and (2) Using portable concrete 3D printers for onsite construction. (ekenel, 2022)

The construction industry is well-matched to 3D printing because the information needed to create a 3D item exists because of the design process, and the industry is already experienced in computer-aided manufacturing. 3D printing provides the ability to use different materials, freedom of design, and the ability to fabricate complex shapes onsite or offsite. (ASTM Committee F42 on Additive Manufacturing Technologies, 2019)

2.3 Benefits

The integration of 3D Concrete Printing (3DCP) heralds a paradigm shift in construction, promising expedited processes and heightened productivity (S. Manjikian, 2020). This advanced technology not only ensures faster and superior construction but also prioritizes environmental friendliness. Embracing 3DCP leads to reduced labor costs, aligning with economic efficiency. Notably, its incorporation provides architects and builders with unprecedented geometric freedom, fostering intricate and innovative designs. As a result, the construction industry witnesses a dual advantage—accelerated timelines and enhanced productivity. 3DCP emerges as a catalyst, reshaping construction practices to embody efficiency, sustainability, and creative freedom in tandem, elevating overall productivity in the built environment.

While the mass customization is the main advantage of 3DP in construction, but the demand for mass customization is still insufficient in construction. Sustainability is an important benefit of 3D printing. 3D printing allows for the design and construction of eco-friendly structures (P Wu, 2016). It also reduces pollution, which is otherwise a common occurrence with traditional construction methods.

The construction industry also has a major role in the emission of carbon in large amounts; the adoption of 3D printing technology will help reduce carbon emissions and also lower energy needs and water wastage. (Abhishek Pandit, 2021)

Houses constructed using 3D printers are more affordable than the ones constructed using traditional methods. As per (Abhishek Pandit, 2021) one storey building constructed using the

traditional method costs around Rs. 8,11,330, whereas the same one storey house if built using a 3D printer will cost Rs. 5,50,000. That shows the significant cost benefit of using 3DCP.
Also, most of the recent trends in construction have shown that clients want innovation in design; they want to experiment with the geometrical patterns and do not want to restrict themselves to the old designs. With the adoption of 3D printing, various designs can be implemented without any repetition. Another benefit is that sometimes weather changes may cause stoppages in work, but with 3D printing, that problem is not a problem anymore. (Pegna, 1997)
These techniques are also able to drastically reduce the lead time to production as well as the cost of design and manufacture of more complex parts that would be difficult or impossible to make with more traditional construction methods. (Han, 2003).
The 3DCP approach also eliminates the need for tooling, enabling swift design changes and product optimization, which, in turn, leads to simplified supply chains, lower inventories, and decreased material usage. Furthermore, it allows for design customization, contributing to increased flexibility and reduced wastage. (Vidarsson, 2015)

2.4 Challenges

3-D printing is not an isolated solution that can solve all the problems in the construction industry. (Peng Wu1, 2016)

Among the social downsides is the impact on the existing construction workforce. The introduction of 3D printing will reduce the number of construction employees required. Although this is a gain because it cuts labour costs, it is a disadvantage for those construction-skilled workers whose jobs are threatened, such as workers pouring concrete and installing steel rebar cages. (Kutay, 2023)

Due to design and material limitations, 3D-printed structures may not meet the expectations of end users at the current technological level. Currently, 3D printing is unsuitable for large-scale endeavours. (Kutay, 2023). The initial cost of the equipment may be expensive. The transportation of the printer is both difficult and relatively expensive. (Kutay, 2023)
Another downside of using 3DP for construction is the restricted availability of suitable materials. In 3D printing, the materials used need to meet certain requirements to be compatible with the technology. (Kutay, 2023). Utilities are not normally included in 3D printing. For example, the fact that building services like plumbing and electrical were not included in the 3D printing process presented a challenge in two Winsun projects. As a result, more work had

to be done, which negatively impacted the structural integrity of the building (P. Wu J. W., 2016)

Also, since this is a new technology, some training needs to be imparted to the workers on how to use it. And there is also a need to employ people who are well-versed in this technology. Training for 3D printing construction becomes more challenging when it comes to remote communities where literacy and numeracy are big challenges. (Kral, 2009).

3D printers consume way more energy than what we can think of, as according to research, they consume 100 times more electrical energy compared to conventional methods. (Abhishek Pandit, 2021).

Additional challenges arise, encompassing the inadequacy of existing automated fabrication technologies for large-scale products, conventional design methods unsuitable for automation, and a notably smaller ratio of final product quantity compared to other industries. Further complications include limitations on materials usable within automated systems, the economic unattractiveness of costly automated equipment, and managerial issues that contribute to the complexity of addressing these challenges. (Skitmore, 2015)

2.5 3DCP in India

3D Concrete printing is at an early stage of development in India (Shaw, 2021). There are few structures being constructed in India utilizing 3DCP. There are very few companies that have showcased 3DCP in India, namely L&T, Tavasta, Simpliforge, and MiCoB. M/s Tavasta has built a Single BHK house at IIT Madras in 21 days (FM inaugurates India's first 3D printed house at IIT-M). M/s. L&T has constructed a post office of 1000 sq feet in Bengaluru in 45 days, including MEP (mechanical, electrical, and plumbing) services (India's first 3D-printed post office inaugurated in Bengaluru). IIT Hyderabad, in collaboration with Simpliforge, has a 3D printed bridge prototype (IIT Hyderabad & Simpliforge build 1st 3D printed bridge). Military Engineering Services has 3D printed a G+1 dwelling unit with of MiCoB in 12 weeks. This disaster-resilient structure complies with Zone 3 earthquake specifications and green building norms (Army hands over first-ever 3D printed houses for soldiers at Ahmedabad).

Some of the structures constructed using 3DCP are shown below.

Figure 2.3 1BHK 3D concrete building by M/s Tvasta image credit Indian express .com

Figure 2.4 Post office constructed by L&T image credit form cnbctv18.com

Figure 2.5 3D printed G+1 building by MiCoB image credit The Economic Times

Figure 2.6 India's First Prototype 3D Printed Bridge by IIT Hyderabad. Image credit- manufactur3dmag

To learn more about the 3DCP in India and have firsthand experience, our team conducted two field visits as part of this project.

2.5.1 Bangalore Post Office Visit

On October 20th, 2023, Dr. Abhishek of IIM Visakhapatnam undertook a visit to the groundbreaking 3D Printed Post Office in Bangalore. During the visit, he engaged with L&T and local staff members of post office, who provided an insightful tour of the facility, delving into the intricacies of the various phases of construction utilizing 3D printing technology and highlighting its comparative advantages over conventional methodologies.

One noteworthy aspect is the broader appeal of the post office, not limited to professionals in the 3D printing and construction sectors. ***This 3D printed post office also has emerged as a unique tourist attraction, drawing individuals intrigued by the innovative application of 3D printing in architectural endeavors.*** This dual significance, both as an architectural marvel and a point of interest for the curious public, underscores the impact of integrating cutting-edge technology into traditional infrastructure.

2.5.2 IIT Madras Lab Visit

Mrs. Arundhati Mech, a member of the NHB Advisory Committee, accompanied by the IIM Visakhapatnam team, including Prof. Srinivas Josyula and Mr. G.V.V.S.S. Avinash, conducted a visit to IIT Madras on 15'th Nov 2023. During their visit, they held a meeting with Prof. Benny Raphael, who serves as a Professor in the Building Technology and Construction Management Division and is the Head of the Civil Engineering Department. While at IIT Madras, the delegation observed various samples of 3D-printed concrete structures at the 3D Concrete Printer Lab. Following the lab tour, the team proceeded to visit the 3D printed house on the IIT campus, a 500 sq. ft. structure created by a startup named Tvasta. This house was printed at Tvasta's Chennai facility and assembled on-site within a remarkable period of 21 days. Mr. Hitesh Meena, co-founder of Tvasta, provided insights into 3D construction processes, recent advancements, consumer awareness, acceptability, and future challenges, including sustainability.

Chapter 3: Design and Development of 3DCP Prototype

In this chapter, we delve into the different steps of crafting and refining a 3DCP Prototype. This prototype becomes a crucial instrument for demonstrating a Proof of Concept (POC) in a tangible and interactive manner, providing a dynamic live showcase for diverse stakeholders. As we navigate the design and development journey, we also express the challenges encountered during this intricate process. By highlighting these obstacles, we aim to offer a comprehensive view of the project's evolution. Our objective remains to breathe life into the abstract concept, allowing stakeholders to engage firsthand, understand the innovative potential, and grasp the implications despite the hurdles faced.

3.1 3DCP Workflow

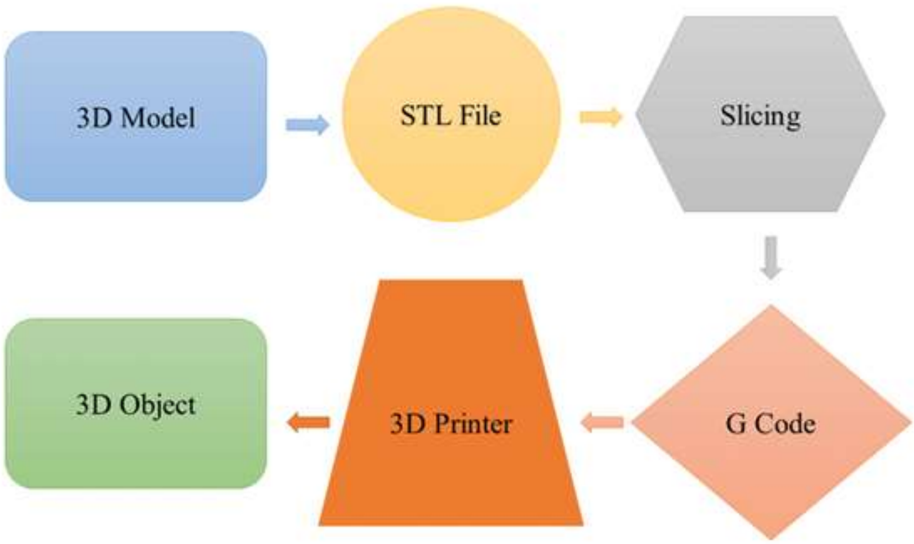

Figure 3.1 Workflow of 3D printing building

To facilitate the 3D printing of an object, a sequence of steps must be adhered to. Initially, a model is crafted using Computer Aided Design (CAD) software such as AutoCAD 3D or TinkerCAD. Subsequently, the model undergoes a slicing process employing slicing software, resulting in the generation of G Code. These G Codes are subsequently input into an application that establishes communication with a 3D printer. The 3D Conceptual Prototype (3DCP) printer then extrudes the material through the print head, executing the printing process based on the prescribed print path dictated by the G Code instructions. This workflow is depicted in Figure 3.1.

3.1.1 3D Model

In this investigation, AutoCAD 3D was employed for the generation of 3D models. The tangible structure slated for printing is meticulously delineated in accordance with its dimensions, as shown in Figure 3.2. Subsequently, these models are exported. stl (Standard Triangle Language or Standard Tessellation Language) files.

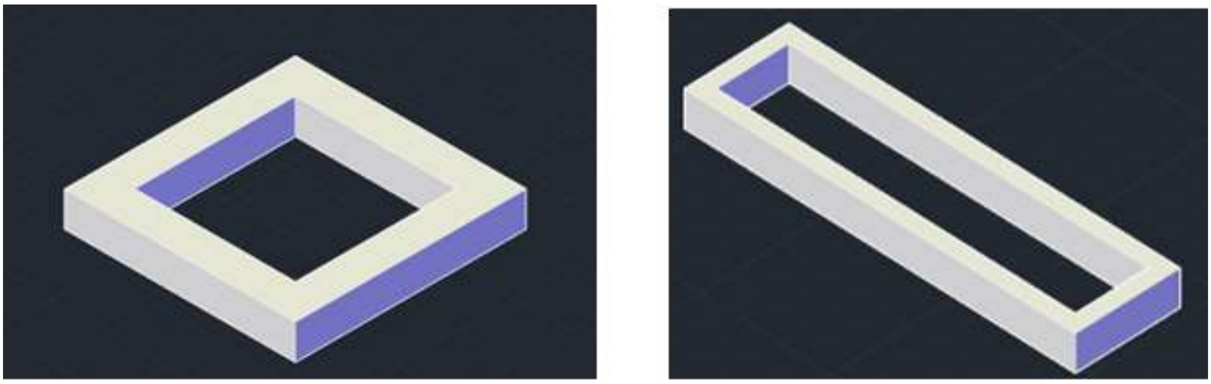

Figure 3.2 Snapshot of model drawn in AutoCAD

3.1.2 Slicing:

This process entails the transformation of the .stl file into distinct printable layers, adjusting the layer height in alignment with the nozzle dimensions. Various applications, such as Cura, Slic3r, Ultimaker, Simplify3D, among others, are available for slicing. In the context of this project, the Slic3r application is employed for slicing the model, as shown in Figure 3.3. Within the slicing phase, parameters such as printing speed, acceleration, and flow can be tailored to suit the specific concrete mix. In our model, a printing speed of 25mm/sec and a flow multiplier of 2 were utilized in accordance with our concrete mix. The slicer then translates these models into G codes,

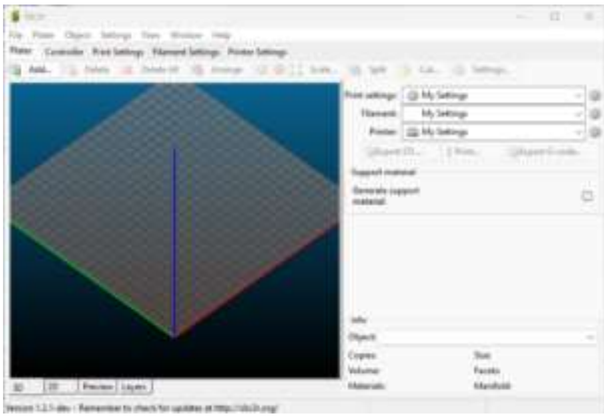

Figure 3.3 Snapshot of application Slic3r

3.1.3 Printing

Subsequently, the G codes are input into a 3D printing application, such as Pronterface or Repetier. In the context of this research, Pronterface is selected for its user-friendly interface. The printing process is then executed through this chosen application.

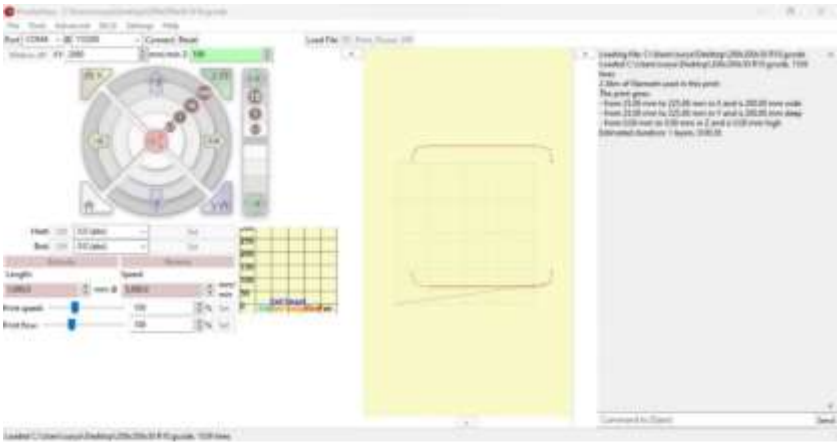

Figure 3.4 Snapshot of application Pronterface

3.2 3DCP Types

There are four main types of 3D concrete printers available on the market.

a. Fixed Robot 3DCP:

This is a conventional robotic arm affixed to a metal frame securely positioned on the floor. It is well-suited for deployment in academic institutions, research facilities, and internal prefabrication production settings.

Figure 3.5 Fixed Robot 3DCP (image credit Cybe Construction)

b. Robotic Crawler 3DCP:

The printer is fixed on a crawler and a hydraulic system. It is a mobile 3D concrete printer that can be transported to any location and maneuver any terrain. The most efficient solution for On-site printing. It can also be used at factories for prefab unit production.

Figure 3.6 Robotic crawler 3DCP (image credit Cybe Construction)

c. Robotic track 3DCP:

The robotic arm is situated on a mobile track, offering an excellent solution for printing sizable objects. This configuration is exclusively applicable for off-site printing.

Figure 3.7 Robotic track 3DCP (image credit Cybe Construction)

d. Gantry 3DCP:

It is a large-scale 3D printer, a perfect factory unit. This can print large-scale prefab units. It can also be used for onsite printing. It cannot make complex structures as the robotic arm is not fixed to the gantry. The required shape is produced by the x, y, and z movement of the nozzle.

Figure 3.8 Gantry 3DCP (image credit Cybe Construction)

3.3 3DCP Prototype Creation

The objective of designing and building a 3DCP prototype is to make a working prototype of a 3D Concrete printer, which we would be able to demonstrate 3D concrete printing to different stakeholders. Large-size 3D printers can be carried out via two mechanisms lead screw driven and rack and pinion. In this project, two designs of 3D concrete gantry printers were explored 1) A gantry-type printer, a system that runs using a ball screw that has a print volume of 825 mm(length) x 825 mm(width) x 825 mm(height). The structural members used are C-beam linear actuators for all axis, which uses Acme lead screws for movement. A total of 5 C-beam linear actuators are used: 1 for the x-axis direction and 2 for both the z-axis and y-axis direction. Each C-beam linear actuator uses a Nema 23 stepper motor of Torque 1.2 N.m.

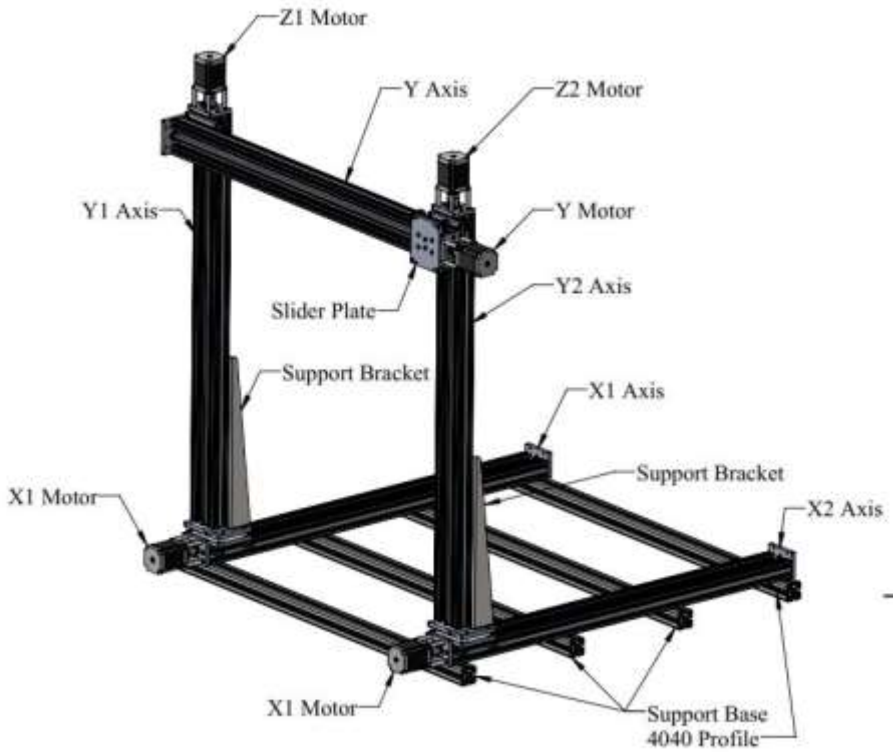

Figure 3.9 Isometric view of miniature 3DCP designed.

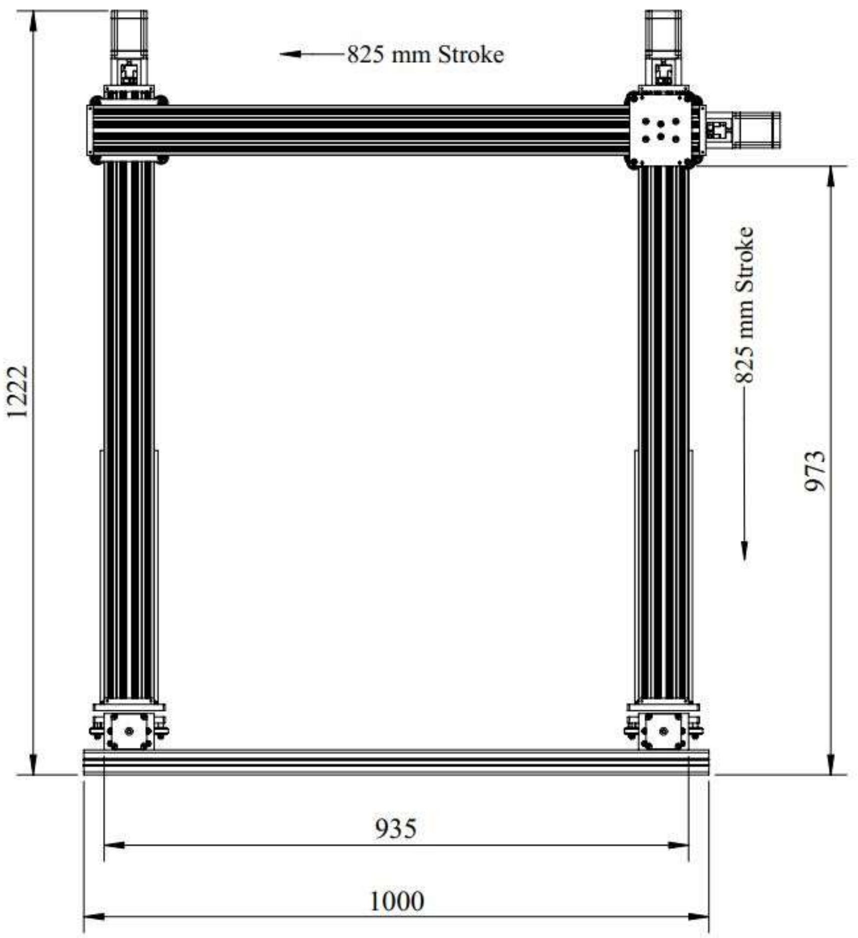

Figure 3.10 Front view of miniature 3DCP designed

This type of 3D printer can carry a load of only 10 kg. So, it requires a concrete grout pump along with it.

2) In the second option, a 3D concrete printer is designed based on a rack and pinion mechanism, which has a print volume of 1000 mm (length) x 1000 mm (width) x 1000 mm (height). The system was designed to carry the concrete load of 32 kgs, assuming a density of concrete is 2500 kg/m3; the load arrives considering in one go the printer can print a layer of

30mm wide and 3.6m length, which is sufficient to print a one and half concrete wall element of 1m length.

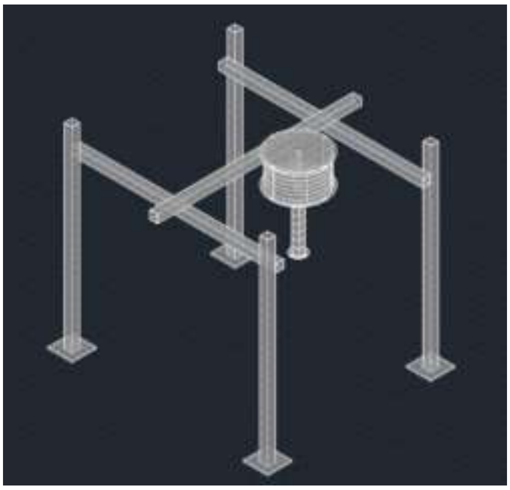

Figure 3.11 Initial Idea of 3DCP

Option 2 was selected for this study as we can get a print height of 1000mm, which is the industry standard for a wall element. The rack and pinion system is more suitable for extension to higher lengths, and there wouldn't be any whiplash observed in larger lengths which are common in ball screws. Also, with this system, concrete can be manually placed into the funnel, which helps us save the cost required for a concrete pump. Moreover, this system will help us to understand the problems and rectify them while planning for a bigger printer.

Even though the 3D printer is made for large sizes, large concrete elements cannot be printed at this stage as the concrete pump and concrete mixer are not under the scope of the project. Concrete must be mixed manually and placed in the nozzle.

Design of 3DCP of Gantry model:

The system was designed to carry the concrete load of 50 kgs considering a factor of safety of 1.5, assuming a density of concrete is 2500 kg/m3; the load arrives considering in one go the printer can print a layer of 30mm wide and 3.6m length which is sufficient to print a one and half concrete wall element of 1m length.

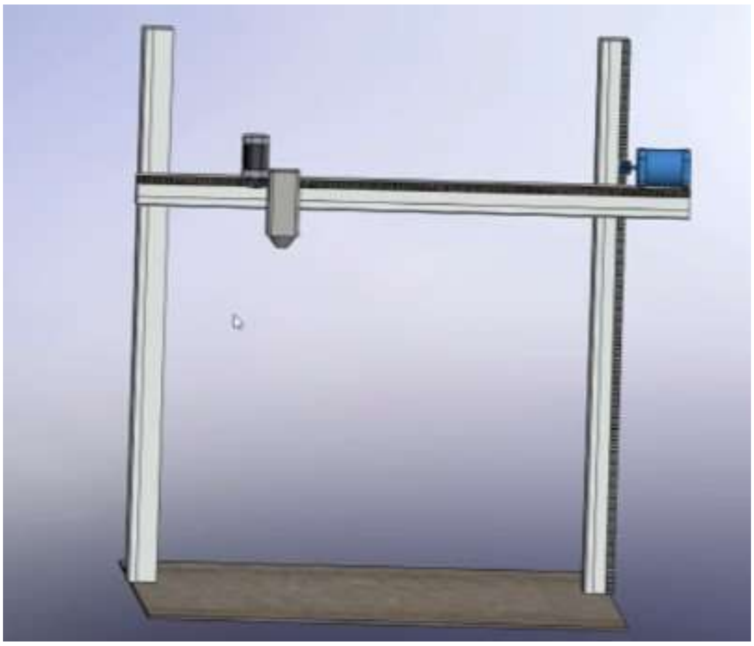

Figure 3.12 Initial design in Solid works

3.3.1 Components used in 3DCP prototype

Structural Frame:

For the main structural members, Aluminum extruded sections were selected because of their lightweight, the possibility of high customization, corrosion resistance, easy installation, and low maintenance. All four vertical members were of 80 mm x 80mm sections, and for three horizontal members, 2 in one y-direction and 1 in the x-direction, 80 mm x 40 mm sections were selected based on their load-carrying capacity and for placement of linear guide rails, stepper motors, and racks. In order for the frame to be structurally rigid, all the vertical members were connected using 80mm x 80mm sections at the bottom and 80mm x 40mm sections at the top.

Fig 3.13 Structural Frame (Aluminium Extrusions)

Linear Guide ways:

In our model, Linear Guideways are used to position the equipment. These consist of two components, namely guide rail and sliding contact guides. HG20 linear guide rail of 1m length and HG20H20CA sliding contact of HIWIN make were selected based on their load carrying capacity. A total of 7 linear guideways were used in the machine: 4 for the Z axis, 2 for the Y axis, and 1 for the X axis.

Fig 3.14 Linear Guide Rail and Sliding Block

Rack and Pinion:

The rack and pinion system were used to carry out the drive mechanism. A helical rack of 1.5 modules and a suitable pinion of 40mm diameter is selected based on the load-carrying capacity. A total of 7 racks were used in the machine: 4 for the Z axis, 2 for the Y axis, and 1 for the X axis.

Fig 3.15 Rack and Pinion

Sliding T-Nut and Allen Bolt

The entire system was assembled using T nuts and Allen bolts. T nuts are fasteners that can slide inside grooves of aluminum extrusions with a suitable diameter hole to receive an Allen bolt; when tightened, this firmly secures the connected members intact.

Figure 3.16 Sliding T-Nut and Allen Bolt

Stepper Motors:

Stepper motors were used as the basic drive mechanism in our system. These are used to achieve precise positioning via digital control. Stepper motors are a type of electric motor whose shaft rotates by a fixed degree upon receiving pulses. In this system, a hybrid stepper motor with a 1.8-degree step angle was chosen as this gives higher torque. A total of 7 stepper motors of Instar make were selected based on the torque carrying capacity. In this machine 85kgcm torque stepper motor of 4 numbers for the Z axis, 28 kg cm torque stepper motor of 1 no. for the Y axis, 11.5 kg cm torque of 1 no. for the X axis, and 28 kg cm torque stepper motor of 1 no. for the nozzle.

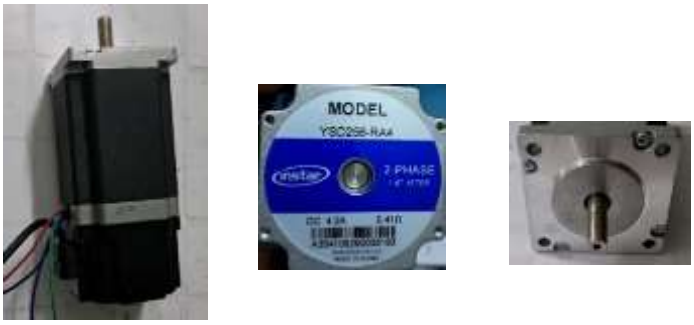

Fig 3.17 Stepper Motor

Stepper Driver

Stepper motor drivers were required for a stepper motor. The pulses received from the controller are converted to current and fed to the stepper motor by the stepper driver. A total of 7 stepper drivers, one for each stepper motor, were used in this system. Stepper drivers have ten dip switches from which current settings and micro step settings can be adjusted as per the requirement.

Figure 3.18 Stepper Driver

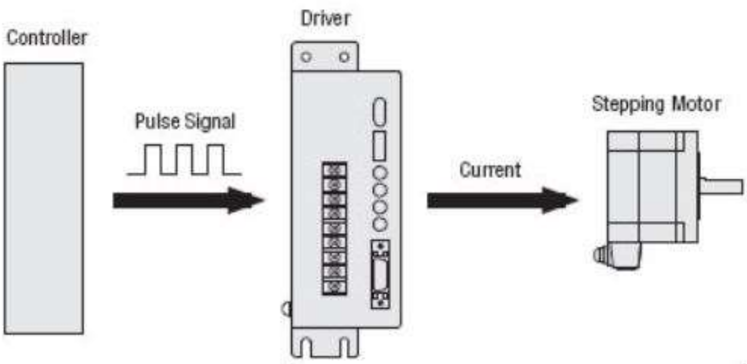

Figure 3.19 Showing Control of Stepper Motor image credit www.orientalmotor.com

Circuit Board:

Makerbase MKS 1.4 Gen L V1.0 is the controller/circuit board used in this machine, as it is suitable for 3D printers and compatible with Marlin's open-source firmware. All the wiring was done as per the circuit wiring diagram.

Figure 3.20 MKS Circuit Board image credit www.makerbase.store

SMPS:

All the stepper motors work on a Direct Current (DC) power supply, so the normal supply from the switchboard Alternating Current (AC) supply has to be converted to a DC power supply using a Switch mode power supply (SMPS). A suitable SMPS of the required voltage and ampere was selected. In this project, 2 Mean well LRS-600-24 were used.

Figure 3.21 SMPS

Brackets:

Brackets were fabricated to connect the nozzle and x-axis, x-axis and y-axis, y-axis, and z-axis.

Fig 3.22 X and Z Motor Arrangement

Limit Switch:

Limit switches are used to set the boundary for the printer on each axis. Whenever a moving part touches the limit switch, it sends a signal to the control unit, and the supply to the motor stops immediately. In this project, mechanical limit switch ME 8108 is used. Separate aluminum brackets were designed and fabricated to place the limit switch at their respective places.

Fig 3.23 Limit Switch

Drag Chain:

For all electrical connections, 1 sq.mm wires were used, and a total of 300 meters length of electrical cables were used in the project. A drag chain was used in order for the cables to move along with the moving parts.

Fig 3.24 Drag Chain

Firmware:

The most important aspect of any printer is firmware. For this study, Marlin, an open-source firmware, is chosen. The firmware is coded for a plastic 3D printer. This is a long code that has more than 7000 lines. It has to be modified to match our 3D concrete printer. Arduino IDE has been used to compile and upload the firmware to the circuit board.

```
// Choose the name from boards.h that matches your setup
#ifndef MOTHERBOARD
  #define MOTHERBOARD BOARD_RAMPS_14_EFB
#endif
// Specify here all the endstop connectors that are connected to any endstop or probe.
// Almost all printers will be using one per axis. Probes will use one or more of the
// extra connectors. Leave undefined any used for non-endstop and non-probe purposes.
#define USE_XMIN_PLUG
#define USE_YMIN_PLUG
#define USE_ZMIN_PLUG

/**
 * Default Axis Steps Per Unit (linear=steps/mm, rotational=steps/°)
 * Override with M92
 *                                      X, Y, Z [, I [, J [, K...]]], E0 [, E1[, E2...]]
 */
#define DEFAULT_AXIS_STEPS_PER_UNIT   { 54, 54, 1.7, 4.16 }

/**
 * Default Max Feed Rate (linear=mm/s, rotational=°/s)
 * Override with M203
 *                                      X, Y, Z [, I [, J [, K...]]], E0 [, E1[, E2...]]
 */
#define DEFAULT_MAX_FEEDRATE          { 300, 300, 5, 25 }

//#define LIMITED_MAX_FR_EDITING        // Limit edit via M203 or LCD to DEFAULT_MAX_FEEDRATE * 2
#if ENABLED(LIMITED_MAX_FR_EDITING)
  #define MAX_FEEDRATE_EDIT_VALUES    { 600, 600, 10000, 50 } // ...or, set your own edit limits
#endif
```

Fig 3.25 Firmware

3.3.2 Components Assembling

All the units were completely assembled, and a 3DCP prototype was made. Initially, all the floor elements were tightened and kept at a level using a spirit level. Care should be taken to keep the elements true to vertical. Then, the vertical members were tightened to the floor elements. Linear Guideways and Racks were attached to the Z structural members. After checking the verticality of the Z structural members, Horizontal elements were attached, which include both Y-axis and X-axis members. Next, Stepper Motors were placed at respective positions along with pinions attached to their shaft, using suitable Stepper motor brackets. Next, the Limit switch was placed at the end position of the racks. All the stepper motors and limit switch wiring were carried out and passed through drag chains where the wires should move along with the motors. Connection to the circuit board, stepper drivers, SMPS, and

Stepper Motor was carried out as per the circuit diagram. The complete built 3DCP prototype is shown in Figure 3.27.

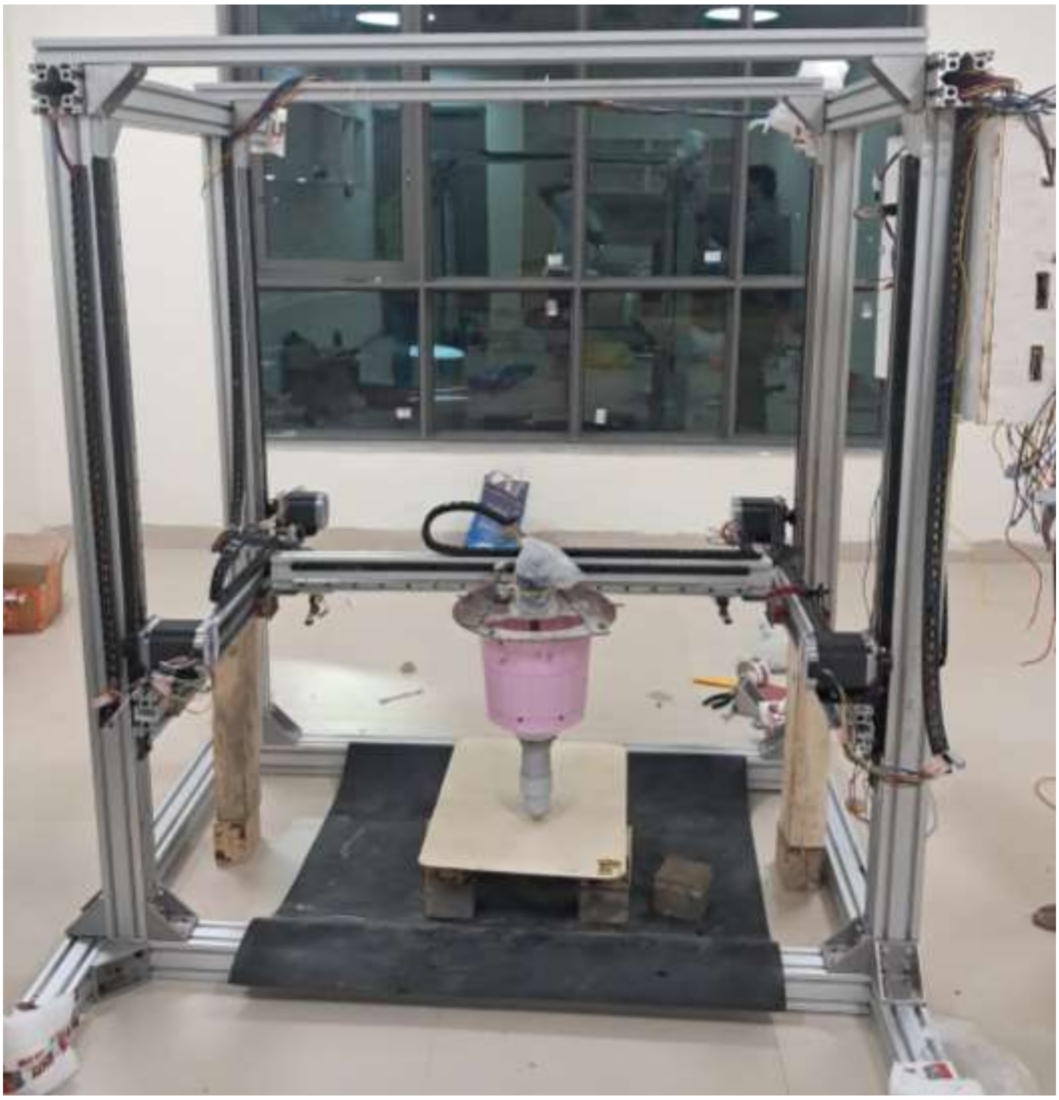

Figure 3.26 3D Concrete Printer

The final specifications of this prototype are summarized in Table 3.1. To make this printer commercially usable, the fixed circular nozzle must be updated to a rectangular rotating nozzle. The 3DCP should also be integrated with a grout pump and a mixer.

Table 3.1- Specifications of 3DCP Prototype

Concrete funnel capacity	12 Liters
Firmware utilized	Marlin
Printable dimensions	1m x 1m x 1m
Concrete layer height	30mm (can be varied)
Concrete layer thickness	30mm (can be varied)
Input Power supply:	220V AC
Drive mechanism	Rack and Pinion
Touch screen and Wi-Fi	Can be enabled
Max aggregate size	2mm

3.3.3 3DCP Concrete Mix

The development of materials suitable for 3DCP is a major challenge. In addition to general properties of concrete like water-cement ratio, aggregate, etc., the following are the key properties of concrete that need improvement in order to successfully 3D print concrete structures. Extrudability, Buildability, and Contact between layers.

a.Extrudability

It is defined as the ability of concrete to travel from mixer to nozzle, which prints in layers without altering the physical properties of concrete. The desired flow of concrete is to be achieved by analyzing the printer speed. Excess deposition of concrete leads to poor surface finish (A.V. Rahul, 2019).

b.Buildability

It is the property of concrete to harden before the next layer of concrete is placed upon the printed layer. Thereby, layers of concrete can be placed upon each other. Factors that affect buildability are chemical admixtures, temperature, and using less gypsum cement. There are two properties of concrete that need modification to adapt to 3D printing conditions. Rapid hardening of concrete after it's placed for the next layer to be placed on top of it and the open time of concrete for the concrete to extrude through the nozzle and not block the pipes. These properties can be achieved by adding chemical admixtures such as accelerators and retarders in varying quantities to the concrete mix. The retarders can be added to the concrete mix while being mixed in the concrete plant to keep the consistency of the concrete. After the concrete arrives at the printing site, the accelerators can be added to the mix right before the printing starts to ensure the rapid hardening of concrete while being printed in layers on top of each other (A.V. Rahul, 2019).

c. Contact between layers

When concrete is placed upon each other, there should be bonding between them to obtain a solid structure. For this, concrete should not completely harden, and the process of hydration should continue before the next layer is placed (A.V. Rahul, 2019).

As there are no readily available propositions, one has to experiment with different ratios of cement, sand, water, and admixture to obtain a mixed design that satisfies the requirements of concrete to be printable. As there are no readily available propositions, one has to experiment with different ratios of cement, sand, water, and admixture to obtain a mixed design that satisfies the requirements of concrete to be printable.

Mix Design:

Mix design is a process of selecting various components and their proportions to meet desired requirements. No standard procedures were available for the development of concrete mix suitable for 3D concrete printers. The selection of material is chosen in concrete mixes that are locally available. For any concrete mix, the ratio of the weight of water to the weight of cement (w/c) is to be decided. As the weight of water required for the complete hydration of cement is 0.28, our w/c ratio should be more than 0.28. For this study, a w/c ratio of 0.32 is selected, and the weight of fine aggregate to the weight of cement is 1.49 (Bhattacherjee, 2020). The quantity of admixture is varied such that we will be able to get an extrudable mix. It is found that for a minimum ratio of wt. of admixture to wt. of cement, 0.14% concrete is extrudable through the nozzle, and below this, the concrete mix is stuck in the nozzle. But the printable mix is not buildable. Mix design is a process of selecting various components and their proportions to meet desired requirements. No standard procedures were available for the development of concrete mix suitable for 3D concrete printers. The selection of material is chosen in concrete mixes that are locally available. For any concrete mix, the ratio of the weight of water to the weight of cement (w/c) is to be decided. As the weight of water required for the complete hydration of cement is 0.28, our w/c ratio should be more than 0.28. For this study, a w/c ratio of 0.32 (Bhattacherjee, 2020) is selected, and the weight of fine aggregate to the weight of cement is 1.49 (Bhattacherjee, 2020). The quantity of admixture is varied such that we will be able to get an extrudable mix. It is found that for a minimum ratio of wt. of admixture to wt. of cement, 0.14% concrete is extrudable through the nozzle, and below this, the concrete mix is stuck in the nozzle. But the printable mix is not buildable.

Table 3.2 Initial concrete mix

S.No.	Material	Description	Kg/Cum
1	Cement	Ramco Super grade PPC	825
2	Sand	Passing through a 2mm sieve	1237
3	Water	Suitable water for construction	264
4	Superplasticizer	Fosroc Aura mix 400	1.09
5	W/C	Water/cement ratio	0.32

In order to decrease the flowability and increase the buildability of concrete, silica fume or nano clay can be added to concrete (A.V. Rahul, 2019). Silica fume and nano clay are mineral admixtures added to concrete. Considering the difficulty in obtaining nano clay, silica fume was selected for this study. Silica fume is an artificial puzzolona that has high puzzolonic activity.

Figure 3.27 Silica Fume

Even in this mix, w/c is kept to 0.32. In these trials, the quantity of silica fumes and admixture was varied. It is found that for the ratio of the weight of silica fume to the weight of cement

0.12 and the weight of the admixture to the weight of cement 0.16%, we are able to get a printable mix.

Printable Concrete Mix:

Table 3.3 Printable Concrete Mix

S.No.	Material	Description	Kg/Cum
1	Cement	Ramco Super grade PPC	738
2	Silica Fume	90% passing through a 45micron sieve	87
3	Sand	Passing through a 2mm sieve	1237
4	Water	Suitable water for construction	264
5	Superplasticizer	Fosroc Aura mix 400	1.39
6	W/C	Water/cement ratio	0.32

Figure 3.28 Printable Concrete mix

There was no standard equipment available to check the compressive strength of fresh concrete. The 28-day compressive strength of the printable mix is tested as per Indian Standard 2250-1981 and found to be 36 N/mm2. The parameters of buildability and extrudability can be measured by the yield strength of fresh concrete and can be achieved when the material yield stress is within a range of 1.5 to 2.5 kph (Rahul, 2018). So, vane shear equipment was used to measure the shear strength of fresh concrete.

Figure 3.29 Vane Shear Apparatus

The above printable concrete mix has been in this range for a period of 5 minutes, from mixing to 35 minutes only. So, we would achieve a printable concrete mix for a time span of only 30 minutes.

3.3.4 Prototyping Challenges

The construction of the 3DCP prototype faced several challenges. There was no publicly available standard reference for implementing a large-scale 3DCP with a rack and pinion drive mechanism. Precise rigidity and leveling of the main frame were required within a narrow tolerance. Locally available major components were scarce, leading to timely procurement and fabrication efforts. Open-source firmware designed for plastic 3D printers had to be adapted, and its trial-and-error nullification process was challenging due to limited documentation. Firmware optimization was necessary to accommodate the higher load-bearing capacity compared to conventional plastic 3D printers. The available open-source firmware is designed for the low load-carrying capacity of 3D printers. Consequently, we couldn't achieve the full holding torque capacity for the Z-axis, which requires comprehensive coding for stepper drivers. Additionally, a higher voltage SMPS is needed for Z-axis motors, which will increase the costs. Standardized codes for concrete mix design suitable for 3DCP were absent, resulting in numerous experimentation rounds. Concrete testing equipment, such as the van shear apparatus, was unavailable locally and required specific procurement. Mineral admixtures like silica fume and nano clay, crucial for enhancing concrete buildability in the 3DCP, were not locally available.

Chapter 4: Stakeholders Perception

The preceding chapters have laid the groundwork by introducing the significance of 3D concrete printing technology in manufactured housing. The subsequent literature review has provided a comprehensive overview of existing studies, technological advancements, and critical considerations surrounding this innovative construction approach.

The primary stakeholders within the housing sector consist of consumers, who are predominantly influenced by architects, builders, and contractors. A symbiotic relationship exists between consumers and builders, with both relying on banks and financial institutions for housing loans and property mortgages and engaging with insurance companies for asset-related solutions. Notably, the academic and research community plays a significant role in fostering technological disruptions and innovations. Their indirect influence shapes the landscape of the construction and housing sector.

Building upon this foundation, the current chapter delves into the heart of our investigation: the analysis of stakeholder perceptions. This section dissects and interprets the collected data from four stakeholders—builders and construction sector professionals, banks and financial institutions, academics and researchers, and consumers.

Data was collected from the identified stakeholders, namely Builders and Contractors within the construction sector, Consumers, Banks and financial institutions, and the Academic and research community through various methods, i.e., via online Google forms, physical forms, Telephonic conversations, and In-person meetings to solicit their views. The Questions included information and stakeholders' perception about the following: Knowledge and Awareness on 3D Concrete printed houses, Perceived benefits, Perceived Challenges, Quality and Durability, Stakeholder Involvement & Skilling needs, Market Adoption, Acceptance & Barriers, and Future outlook. The tables 4.1 to 4.4 and graphs 4.1 to 4.4 summarize the overall descriptive statistics of the respondents.

20 to 30 years	29
30 to 40 years	39
40 to 50 years	7
Above 50 years	5

Table 4.1 Age distribution of respondents

Female	13
Male	65

Table 4.2 Gender Distribution of Respondents

Graduate	25
Postgraduate	48
Doctorate	7

Table 4.3 Education Level of Respondents

Banking & Financial Institutions	3
Builders and Contractors	37
Consumers	23
Research & Academia	17

Table 4.4 Stakeholder Distribution of Respondents

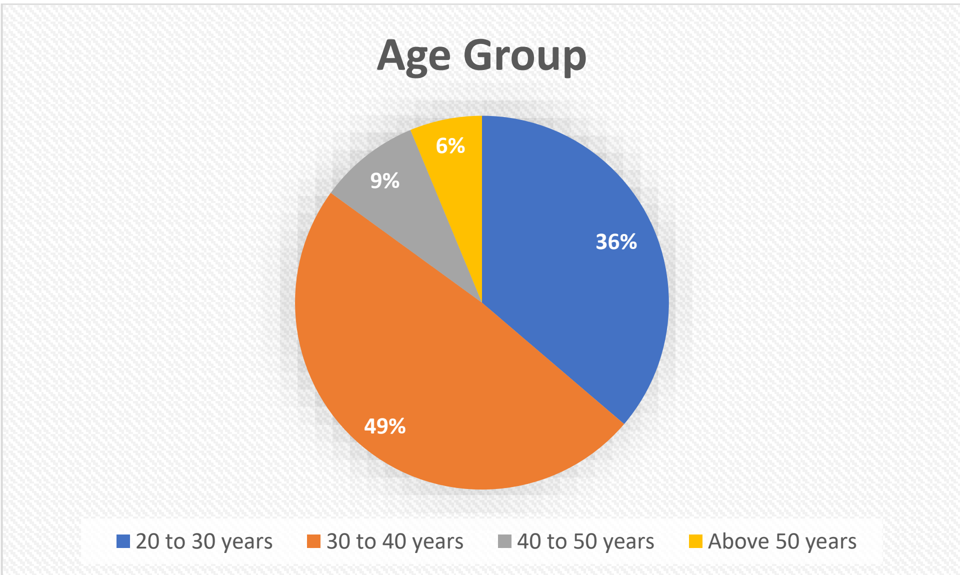

Fig 4.1 Age distribution of respondents

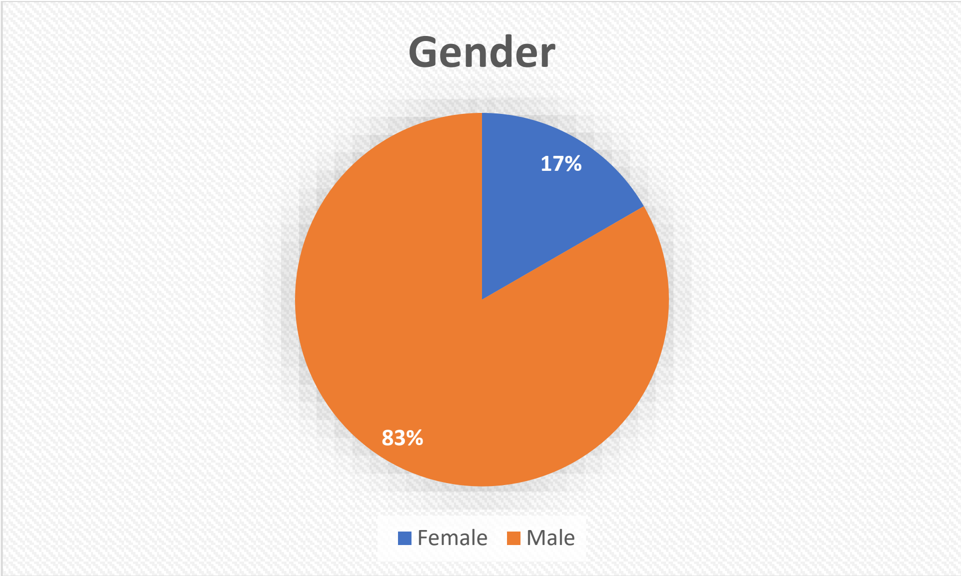

Fig 4.2 Gender distribution of respondents

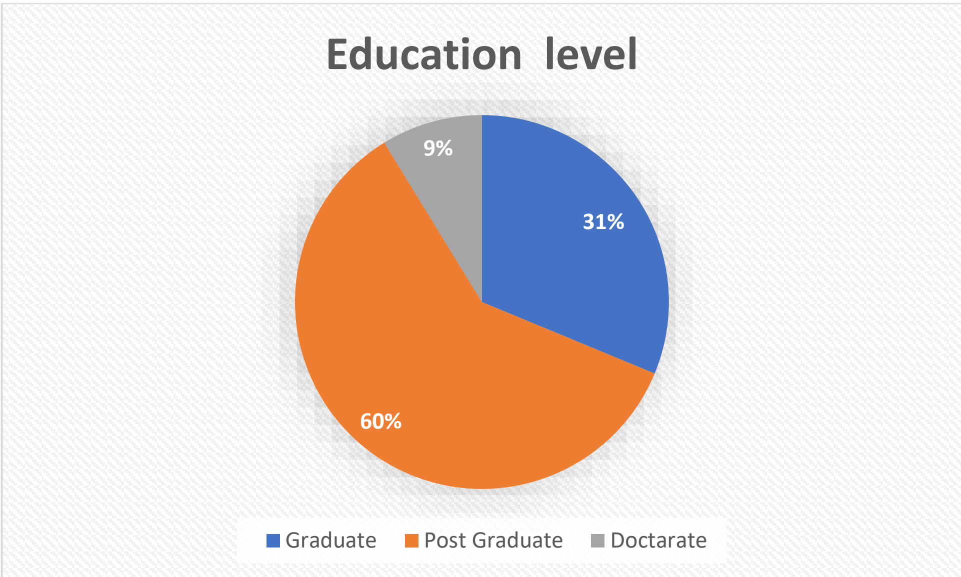

Fig 4.3 Education level of respondents 1

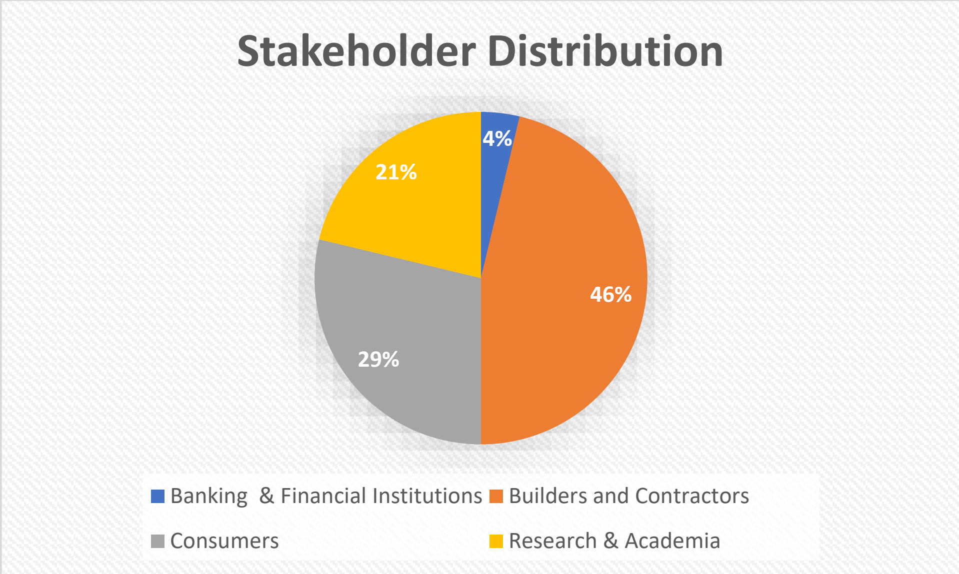

Fig 4.4 Stakeholder distribution

4.1 Consumers

While Consumers are the critical stakeholders in the housing value chain, they are influenced by the Architects, Builders, and Contractors to keep them informed about the features, technology adoption, and the Banks and Financial Institutions who provide financial and Insurance solutions for housing Assets.

The following are the salient observations/ perceptions based on the responses received for the questionnaire, interviews, and the analysis of the data.

Consumer perceptions of 3D concrete printing for housing construction in India exhibit a wide spectrum of perceptions and attitudes. While some are optimistic about its potential impact, others note a slow pace of acceptance of this disruptive technology adoption. A recurring theme is the expectation that broader adoption will occur when the technology is implemented on a larger scale. Concerns about initial low acceptance are tempered with expectations of growing awareness and acceptance over time, potentially through government-backed demonstration projects. Quotes/ statements like "*Acceptance at a very slow pace*" and "*Still in the nascent stage*" capture the sentiments of consumers.

Consumer concerns center around the lack of regulatory hurdles, public perceptions, and financial considerations. Regulatory and perception-related challenges are cited as potential barriers, indicating a need for clear communication and understanding. Significant concerns about costs, including high initial expenses and limitations in constructing multi-story buildings, underscore the economic considerations for consumers. Additionally, logistical challenges in remote areas and the importance of creating awareness and a reliable track record are highlighted. Quotes such as “*Regulation and perception of people*” and “*High cost and limitations related to the construction of multi-storied buildings*” reflect these consumer apprehensions.

While there is optimism and anticipation for the technology's potential, a significant portion of consumers express reservations, emphasizing the need for targeted efforts to address their concerns. In summary, consumers display a range of sentiments, from optimism to cautiousness, reflecting the varied levels of awareness and understanding of 3D concrete printing technology. The successful adoption of this technology hinges on addressing financial concerns, enhancing public awareness, and navigating regulatory landscapes.

4.1.1 Knowledge and Awareness

Consumers present a nuanced understanding of 3D printing in construction, recognizing its potential for "reducing cost and time before going to construct something" and its utility in constructing small parts or equipment. One respondent emphasizes its significance as the "*need of the hour,*" highlighting its fast and efficient construction capabilities. Another perceives it as a "*budding invention*" with unique features like timesaving, less manpower utilization, and customizable designs.

Familiarity with 3D concrete printing in housing construction varies, with some respondents acknowledging exposure to specific projects. One respondent vividly recalls, "*I came to know about a post office in Bengaluru that was constructed in just 45 days... the moment I heard it, I thought what a revolution it was.*" Online videos and media stories contribute significantly to consumers' awareness, with mentions of L&T and startups using 3D printing for construction. Real-world encounters, like watching construction projects online, leave a lasting impact. However, some consumers express limited familiarity or beginner status. Overall, media representation significantly shapes consumer knowledge, with concrete examples like the Bengaluru post office serving as memorable instances that contribute to their awareness of 3D concrete printing in housing construction.

4.1.2 Perceived benefits

Consumers exhibited keen interest in the transformative potential of 3D concrete printing and foresee numerous benefits that align with their expectations for cost-effectiveness, efficiency, and safety.

The desire for cost reduction is evident in quotes such as *"Decrease the construction cost"* and *"Faster construction,"* highlighting the consumers' anticipation of a more economical construction process. This financial consideration aligns with the broader expectation of achieving a *"life span of the building"* through the cost-effective implementation of 3D printing technology.

Accessibility and customization emerge as significant themes, with consumers expressing enthusiasm about the technology's ability to construct *"complex structures easily"* and in *"remote locations."* These quotes underline the consumers' aspirations for expanded accessibility and personalized design choices, making 3D-printed houses an attractive prospect for diverse construction needs.

Safety considerations are paramount, with consumers noting the potential of 3D printing to *"avoid accidents during the traditional construction method."* This safety-driven perspective aligns with their desire for construction processes to be *"fast and effective,"* showcasing an emphasis on both efficiency and worker well-being.

Sustainability becomes a key factor, with consumers recognizing the potential of 3D printing to *"reduce material waste by using only the necessary amount of construction material."* This acknowledgment reflects a broader societal consciousness about environmentally friendly construction practices.

Despite these positive perceptions, cost challenges are acknowledged, with consumers stating that the *"cost of this method is at present more and very higher when compared to traditional methods."* This nuanced perspective reveals a pragmatic awareness of current limitations, suggesting that cost considerations must align more closely with consumer expectations to realize the full potential of 3D concrete printing.

4.1.3 Perceived Challenges

Consumers expressed multiple concerns about the adoption of 3D concrete printing in housing construction. The foremost challenge highlighted is *cost*, with respondents perceiving 3D printing technology as more expensive than traditional construction methods. One respondent emphasizes this, stating, *"when compared to traditional construction methods, the cost involved is more which people from the middle class and lower-middle-class economy may not be able to afford."* This cost concern is intertwined with the broader issue of *acceptability*, particularly in rural areas where there might be skepticism about the quality of 3D technology. Respondents suggest that overcoming this challenge necessitates the development of *demo projects* to showcase the advantages of 3D printing firsthand. Additionally, there are calls for addressing *regulatory and technical concerns*, including the need for standardized regulations and codes. The responses underscore the importance of addressing financial, acceptability, awareness, and regulatory challenges to facilitate the widespread acceptance of 3D concrete printing in housing construction.

4.1.4 Quality and Durability

Consumers are generally optimistic about the quality and durability of 3D printed concrete structures, with one respondent stating, *"The construction would be strong, and durability depends on the material used,"* reflecting confidence in the technology's strength. Another consumer expresses positivity, noting, *"Quality would be uniform, which will be better and durable,"* suggesting an expectation of consistent and improved durability. However, there are contrasting views, as indicated by the remark, *"Durability might be an issue,"* reflecting some reservations. To address concerns, a consumer emphasizes government involvement, suggesting, *"The government should take the lead… using 3D technology to improve its acceptance,"* underlining the need for broader initiatives to enhance public confidence. Overall, while optimism prevails, acknowledging some skepticism emphasizes the importance of addressing consumer doubts through awareness and collaborative efforts.

4.1.5 Stakeholder Involvement & Skilling needs

Consumers perceive 3D concrete printing as a disruptive technology with transformative implications for the construction industry. The majority recognizes that unskilled labor may be significantly affected, signaling a potential shift in traditional roles. There's a consensus that architects and engineers will remain essential, but the demand for traditional contractors and laborers might decrease. Respondents expressed the view that the implementation of the technology could streamline the construction process, reducing the need for continuous monitoring and input from various stakeholders.

In terms of skilling needs, consumers emphasize the necessity for new skill sets and training programs. There is a shared understanding that 3D printing technology is still emerging, and there is a lack of awareness, knowledge, training, and skills among professionals entering this domain. Suggestions include the introduction of basic skill set training and awareness programs to equip professionals for the nuances of 3D concrete printing. The idea of incorporating courses in ITI, polytechnic colleges, and Engineering programs highlights a proactive approach to addressing the evolving needs of the construction industry. This sentiment is also captured by one respondent who stated, "*Unskilled and labor would be affected more,"* highlighting the anticipated impact on traditional roles. Another respondent expressed optimism, stating, "*Revolutionize the construction industry*," emphasizing the transformative potential of 3D concrete printing. Additionally, there is a recognition that "Architects and engineers are still necessary," reflecting the nuanced evolution of professional roles in the construction sector. The call for "basic skill set training and awareness about 3D printing for professionals getting involved in it" underscores the proactive stance toward addressing emerging skilling needs. Finally, the proposal for introducing a course in ITI and polytechnic colleges and Engineering programs aligns with the broader theme of preparing professionals for the paradigm shift in construction practices.

4.1.6 Market Adoption, Acceptance & Barriers

Consumer perceptions of 3D concrete printing for housing construction in India exhibit a spectrum of attitudes. While some express optimism about its potential impact, others note a slow pace of acceptance. A recurring theme is the expectation that broader adoption will occur when the technology is implemented on a larger scale. Concerns about initial low acceptance are tempered with expectations of growing awareness and acceptance over time, potentially through government-backed demonstration projects. Quotes like “Acceptance at a very slow pace” and “Still in the nascent stage” capture these sentiments.

Consumer concerns are around regulatory hurdles, public perceptions, and financial considerations. Regulatory and perception-related challenges are cited as potential barriers, indicating a need for clear communication and understanding. Significant concerns about costs, including high initial expenses and limitations in constructing multi-story buildings, underscore the economic considerations for consumers. Additionally, logistical challenges in remote areas and the importance of creating awareness and a reliable track record are highlighted. Quotes such as “Regulation and perception of people” and “High cost and limitations related to the construction of storied buildings” reflect these consumer apprehensions.

While there is optimism and anticipation for the technology's potential, a significant portion of consumers express reservations, emphasizing the need for targeted efforts to address their concerns. In summary, consumers display a range of sentiments, from optimism to cautiousness, reflecting the varied levels of awareness and understanding of 3D concrete printing technology. The successful adoption of this technology hinges on addressing financial concerns, enhancing public awareness, and navigating regulatory landscapes.

4.1.7 Environmental Impact & Sustainability

Consumers exhibit a cautiously optimistic outlook on 3D concrete printing, highlighting the potential for cost reduction and faster construction. The majority express a positive stance, emphasizing benefits such as environmental friendliness through reduced material wastage and enhanced efficiency.

"Reducing cost faster the time of construction," "Environment friendly,"

However, a portion remains uncertain, stating a lack of awareness and indicating a need for time for public acceptance, as evident through responses like "I don't know," "No idea," "I don't think so," and *"No. "* Concerns about the establishment of a reliable supply chain and the importance of government adoption are noted as expressed through - *"Establishing a supply chain will be challenging. "* While the majority sees the technology favorably, few voice reservations, citing the need for more information and expressing skepticism. *"I don't think so," No,"*

Overall, consumer sentiments indicate a desire for transparency, government endorsement, and further awareness to build trust in the innovative 3D concrete printing method.

4.1.8 Future Outlook

Consumers are *optimistic about the future* of 3D concrete printing, seeing it as a disruptive and transformative technology for the construction industry. They express the desire for *reduced costs and increased affordability*, emphasizing the need for 3D printing projects to be more accessible. As one consumer suggests, "*Cost should be reduced, more building solutions.*" There is also a curiosity about the capabilities of the technology, with some consumers wanting to understand if multi-story buildings can be constructed using this method. Additionally, consumers stress the importance of advancements, such as the use of more eco-friendly materials and the demonstration of quality and affordability through demo projects. Quotes like "*May use more eco-friendly materials for construction*" reflect this desire for sustainable practices. Furthermore, consumers suggest a collaborative platform where different stakeholders can contribute their views to enhance 3D printing projects. This collaborative approach aligns with their overall interest in exploring the full potential of 3D concrete printing in the housing construction sector.

4.2 Builders and Contractors in the Housing Sector

Architects, Builders, and Contractors are critical links in the housing sector value chain as they wield influence over consumers. They educate Consumers on the disruptive technologies adopted in their housing projects, compliance with regulations and standards, innovative designs, quality construction, and transparent communication, fostering trust. They can shape consumer preferences and choices by creating aesthetically pleasing, functional spaces. Additionally, these professionals play a crucial role in influencing banks and financial institutions by showcasing the viability and reliability of their projects. Clear project plans, adherence to regulations, and a proven track record enhance their credibility, making them attractive partners for financial entities. This symbiotic relationship between industry professionals and financial institutions is pivotal for successful housing projects and financial collaborations.

The following are the salient observations/ perceptions based on the responses received for the questionnaire, interviews, and the analysis of the data.

4.2.1 Knowledge and Awareness

Architects, Builders, and Contractors in the Housing Sector showcase varying levels of understanding regarding 3D concrete printing technology. A prevailing sentiment is the recognition of 3D printing as a disruptive and "advanced technology in the construction field" with the potential for "reducing wastage of material" and providing "geometric freedom." There is an acknowledgment of its efficiency, with phrases like "ease of construction" and "time-saving process."

Some respondents have expressed awareness about the ongoing research, citing L&T's involvement in 3D technology for building construction. Familiarity levels range from basic to moderate, often acquired through online sources and media coverage. Concrete examples of 3D concrete printing projects mentioned include the construction of a post office in Bengaluru, an IIT Madras building, and structures by Godrej.

On the other hand, a few of the respondents admit to limited familiarity or lack of direct experience with 3D printing technology. Some express curiosity, indicating interest in exploring the technology despite not encountering such projects directly. Overall, the majority opinion reflects positive sentiments, emphasizing the potential benefits and advancements brought by 3D concrete printing in the construction sector.

4.2.2 Perceived benefits

Architects, Builders, and contractors in the housing sector are integral stakeholders in the realm of 3D concrete printing adoption for housing sector units, as they recognize the disruption that this technology will bring in the Housing/ Construction sector and the spectrum of compelling benefits in the technology. Key advantages of the adoption of new technology would include notable reductions in costs, increased time efficiency, operational streamlining, material conservation, precise design capabilities, geometric freedom, and improved coordination. One contractor underscores the transformative potential, stating, *"Can address issues of large labor requirement, time, and cost overruns. Can also make interesting forms and experiments* *possible which were not easy to deliver earlier."* Another emphasizes the efficiency gains, affirming, *"With 3D Printing, all the details will be finalized in advance, with no issues of coordination of services. No delays are anticipated due to a lack of details during construction."* These first-hand perspectives illustrate the significant positive impact that 3D concrete printing can bring to construction practices, reflecting optimism and potential for innovation in the industry.

4.2.3 Perceived Challenges

Builders and contractors, as critical stakeholders in the construction industry, express a range of concerns and challenges related to the adoption of 3D concrete printing technology. These challenges span various aspects, each playing its role in influencing the widespread acceptance and integration of this disruptive yet innovative construction method/technology.

One paramount concern revolves around *structural integrity*. Builders question the seamless integration of different 3D-printed parts while maintaining the overall structural design. An important quote underscores this: *"How different parts of 3D printing objects will be made together and make a complete structure without compromising structural design...what solution shall be used for joining not sure..."*

Another significant challenge involves ensuring the *durability and quality* of 3D-printed structures. Builders emphasize the need for specialized manpower to guarantee the longevity and high quality of such constructions, emphasizing *"Durability, quality."*

The feasibility of constructing *multi-floor structures* using 3D printing technology raises considerable doubt/ concern among builders. The quote, *"Whether we can do multi-storied construction using this 3D printing?,"* reflects the industry's uncertainty about the practicality of vertical expansion through 3D printing.

Awareness and acceptance present additional hurdles as builders acknowledge a potential lack of awareness and the slow pace of public adoption and acceptance. The quote, *"Acceptance by the general public to use new technology, and it may take time to adopt,"* encapsulates the industry's recognition of the uphill battle in convincing the public of the merits of 3D concrete printed housing units.

The challenges extend to practical aspects like *flexibility for remodeling* and the manual, time-consuming nature of finishing works. The quote, *"No flexibility of remodeling at a later stage, use of local material, finishing works still are manual and time-consuming,"* sheds light on the limitations in adapting 3D-printed structures after their initial construction.

A fundamental concern in a developing context like India surrounds the potential *loss of jobs* in the construction industry due to the automation introduced by 3D concrete printing. The quote, *"One major issue that the technology will throw up is the loss of jobs in the construction industry, which is a huge informal labor market,"* highlights the social and economic impact of this technological shift.

Logistical challenges, including space constraints, transportation issues, and regulatory requirements, also feature as prominent concerns. The quote, *"Space constraints to place the 3D printing machines. Buyers will be hesitant to adopt. Height of the superstructure. Can you build 2 storeys? Three storeys? Installation of electrical and plumbing systems in the house"* emphasizes the practical difficulties in implementing 3D printing technology on construction sites.

Technical expertise and training, cost concerns, regulatory compliance, public perception, and material quality all contribute to the complex landscape of challenges faced by builders and contractors in embracing 3D concrete printing in the Indian Context. Despite these obstacles, the industry remains optimistic about the transformative potential, urging the need for comprehensive solutions to drive the widespread adoption of this innovative construction method.

4.2.4 Quality and Durability

Builders and contractors exhibit diverse perspectives on the quality and durability of 3D-printed concrete structures compared to traditional methods. Some anticipate improvements, emphasizing "*Quality and Durability may improve compared to traditional construction...without compromising on structural design concepts.*" However, a segment prefers *conventional methods*, reflecting skepticism or a conservative stance. Optimistic builders foresee *better quality* with 3D printing, citing improved planning capabilities: "*Better as more planning can be done in the office and the dependencies are worked out and procured in advance in view of the speed of work.*" Despite optimism, a significant number express *uncertainty*, with quotes like "*Cannot comment*," indicating reservations. Material considerations vary, with suggestions for *polycarbonate innovation* for strength and durability. Transparency concerns arise: "*Traditional methods are more durable; in 3D printed concrete, one cannot know what materials are used.*" Questions about 3D printing's adaptability to *climate-specific construction* underscore diverse concerns. Finish quality comparisons reveal nuanced perspectives: "*Finish quality of 3D printed concrete is not as good as traditional concrete. Strength and durability may be better than traditional concrete.*" Views on *quality* *control and durability* are mixed, highlighting the need for further exploration and understanding of builders' expectations and concerns in adopting 3D printing technology.

4.2.5 Stakeholder Involvement & Skilling needs

The prevailing sentiment among builders and contractors regarding the impact of 3D concrete printing on stakeholders is optimistic, with a majority expressing positive anticipation. The belief is that 3D printing will bring about disruption in the market and transformative changes, offering *increased freedom* and creative possibilities for stakeholders. The quote, " *I think architects will be able to design and create with greater flexibility and creativity, both aesthetically as well as functionally. Contractors will find it cost and time-effective to deliver. However, architects and engineers may have to undertake experimentation and R&D to ensure structural stability*" encapsulates this positive outlook, highlighting an optimistic view of the technology's potential impact.

Additionally, the acknowledgment of the need for upskilling and learning the nuances of the new technology, as indicated by the quote, "*All of them will need to upskill and learn the nuances of and the possibilities with the new technology,*" underscores a willingness to adapt to the changes brought about by 3D printing. This aligns with the overall sentiment of openness to embracing new skill sets and training.

While there are diverse opinions and some expressions of uncertainty or challenges, these quotes support the overarching theme of positive anticipation and a belief in the transformative potential of 3D concrete printing on stakeholders in the construction industry. The majority's positive outlook is complemented by the recognition of the need for adaptation and skill development, indicating a readiness to embrace the advancements offered by 3D printing technology.

4.2.6 Market Adoption, Acceptance & Barriers

Builders and contractors exhibit a cautiously optimistic outlook on the market acceptance and adoption of 3D concrete printing for housing construction. A significant proportion expresses positive sentiments, anticipating high or moderate acceptance levels. However, a degree of skepticism and uncertainty persists, with some acknowledging the need for progress in technology setup, standardization, and awareness to boost acceptance. One respondent emphasizes, "*Market will accept it; only thing 3dcp technology setup progress and standardization required to be done.*" The perception is that wider acceptance may be contingent on government initiatives, proper advertisement, and detailed publications to educate the public and industry stakeholders, as expressed by a response, *“I think governments* *will have to take the initiative and get its own buildings 3D printed. Like schools, health centers, offices etc. and popularise it",* which is visibly happening in the Indian context

Several barriers and factors that could impede widespread adoption are identified. Government support is deemed crucial, and concerns about the regulations, standards, quality, cost, and technical aspects of the technology are prominent. The *lack of skilled professionals* and *public awareness* emerge as significant obstacles, reflecting the need for extensive training programs and marketing efforts. High initial investment costs and the challenge of integrating service lines are recognized as potential barriers. A respondent notes, " *I don't think there are a lot of professionals who can implement this technology.*." Quality concerns, including standards and regulations, perception of strength and durability, and potential environmental impacts, are highlighted as potential barriers to widespread adoption.

4.2.7 Environmental Impact & Sustainability

The majority of builders and contractors express optimism about the environmental benefits of 3D concrete printing in housing construction. They anticipate a reduction in raw material consumption, leading to minimized waste compared to traditional methods. *"Less consumption of raw materials...may reduce wastages...potential benefit to the environment"* reflects the prevalent positive sentiment.

However, a few have expressed concerns regarding the technology's sustainability. Some worry about the inability to use local materials for mortar, substantial power requirements for the binding material, and limitations in sustainability practices. *"Local materials cannot be used...binding material requires a lot of power...sustainability concerns"* outlines the apprehensions related to material choices and energy consumption.

In terms of sustainability-related concerns, few builders also highlight issues such as repairability, modifiability, and difficulties in employing local labor. Challenges include restrictions on using large aggregates, limiting powdering materials' potential, and facing difficulties in repair and modification compared to traditional methods. *"Repairability and modifiability are lesser than RCC framed structures...local labor employment is difficult,"* outlines the sustainability-related challenges faced by a few.

While the majority expressed confidence in the positive environmental impact, it is essential to consider the concerns raised by a few, emphasizing the need for addressing technological and material limitations to enhance the sustainability aspects of 3D concrete printing in housing construction.

4.2.8 Future Outlook

Builders and contractors express a positive outlook on the future of 3D concrete printing (3DCP) in housing construction. The majority anticipate its widespread adoption, viewing it as a disruptive and revolutionary technology with the potential to address challenges like labor shortages and construction speed. Quotes such as *"It's a must, cannot be avoided to grow"* and *"I myself will be a regular client"* reflect enthusiasm and belief in 3DCP's capability.

In terms of advancements, stakeholders desire comprehensive development across the entire 3DCP ecosystem, including construction materials, machine standardization, and overall technology setup. The sentiment is captured by quotes like *"Yes, complete technology setup: construction materials, 3dcp machine, standardization, etc"*, indicating a holistic approach to technological progress.

The respondents also emphasize the need for awareness and education. They suggest online sessions to create public awareness and propose integrating 3DCP into the engineering curriculum, highlighting the dependence of Industry on the Academic fraternity to supply qualified engineers who can ably use the 3DCP technology. The call for education is evident in quotes such as *"Online sessions need to be conducted to create awareness among the public"* and *"It should be a part of engineering curriculum along with regular courses."* These quotes underline the importance of knowledge dissemination for the successful integration of 3DCP.

Lastly, the recommendations for further research cover a spectrum of topics, from the structural strength of materials to exploring their applications in high-rise structures. Quotes like *"Materials that can take tension, reinforcing parts of the structure"* and *"Maybe the technology can be adopted for high-rise structures"* indicate a collective interest in exploring the full potential of 3DCP.

In summary, builders and contractors express optimism for the future of 3D concrete printing in housing construction, with a focus on comprehensive advancements, education, and further research to unlock its full potential.

4.3 Banks and Financial Institutions

Banks and financial institutions are the backbone of the housing sector, providing essential capital for construction and home acquisition. Through loans and financial instruments, they enable homeownership and manage risks, ensuring a smooth flow of funds for ongoing development. Their influence extends to interest rates, real estate investment, and policy implementation, shaping a dynamic housing landscape.

Further, Banks and financial institutions play a pivotal role in influencing architects, builders, contractors, and consumers in the construction sector. They can provide tailored financial products, such as incentives and preferential loan terms, to architects, builders, and contractors adopting sustainable and innovative practices. Offering financing for continuing education programs for professionals fosters expertise in modern construction technologies. For consumers, providing accessible loans and mortgage solutions for eco-friendly and technologically advanced homes encourages the adoption of sustainable practices. Collaborative efforts with industry stakeholders, including educational institutions, can further promote a holistic approach to advancing the construction sector with an emphasis on innovation, sustainability, and financial viability.

The following are the salient observations from Banks and Financial Institutions including Insurance companies, based on the responses received from the questionnaire, interviews and the analysis of the data.

4.3.1 Knowledge and Awareness

Bankers and financial Institutions demonstrate limited awareness and understanding of 3D concrete printing technology. Responses indicate a lack of direct familiarity with terms like "new to this area" and a general description of "generating a physical object by layering." Moreover, respondents express no direct exposure to 3D concrete printing projects in the housing construction sector. The consensus suggests a baseline knowledge level, with terms like "basic" and a lack of specific details regarding the technology's application.

In contrast to stakeholders directly involved in construction, bankers and financial institutions may have a more peripheral understanding of 3D concrete printing. Their responses imply a need for more information and exposure to the technology. This limited awareness may influence their decision-making processes related to funding or investment in construction projects incorporating 3D concrete printing.

4.3.2 Perceived benefits

Bankers and financial Institutions envision "low-cost benefits" in 3D concrete printing, emphasizing its financial viability. The acknowledgment of challenges is apparent as they note the difficulty in setting up 3D printers for "constructing large-scale high-rise towers (30 floors)." While expressing a positive outlook with "good future prospects," concerns about time efficiency are voiced, stating that "3D printing would be a time-consuming process compared to traditional methods." This pragmatic stance reflects financial stakeholders' careful consideration, weighing potential benefits against challenges and prioritizing cost-effectiveness and efficiency in the adoption of 3D concrete printing in housing construction.

4.3.3 Perceived Challenges

Bankers and financial Institutions express reservations, citing challenges in public acceptance due to the novelty of 3D concrete printing. Concerns about time-consuming large-scale printing, high setup costs, and regulatory approvals are evident. The quote, "New concept, so it will take time to be acceptable to the public in general," reflects apprehensions about public reception. Additionally, the emphasis on making people aware of the technology's pros and cons underscores strategic concerns. While recognizing potential hurdles, financial stakeholders advocate for proactive efforts in public education to address perceived challenges in adopting 3D concrete printing for housing construction.

4.3.4 Quality and Durability

Bankers & Financial Institutions recognize 3D-printed concrete structures as an upgraded construction technology. However, concerns about achieving the desired quality and fine finish through layering are evident. The quote "*quality would be low as the desired fine finish would not be possible by layering*" captures reservations about the aesthetic aspects. While acknowledging advancements, there's a cautious view about certain quality considerations compared to traditional construction methods.

4.3.5 Stakeholder Involvement & Skilling needs

Bankers and financial Institutions exhibit diverse views on the potential impact of 3D concrete printing on construction stakeholders. While some foresee challenges, as evidenced by a quote, “Yes, there will be challenges to the architects' engineers, etc., “others downplay its effects. In terms of skilling needs, a majority acknowledge the necessity for new skill sets, recognizing the emerging technology's demand for updated expertise: "Yes, new skill sets required." This consensus highlights the perceived importance of skill development to align with the evolving construction landscape.

4.3.6 Market Adoption, Acceptance & Barrier

Bankers and financial institutions express a cautious stance regarding the market acceptance and adoption of 3D concrete printing in housing construction. One respondent notes that it "*will take time to be acceptable to the public in general,*" reflecting a gradual acceptance outlook. Another response indicates a perception of "*Low*" market acceptance. The quotes underscore a sense of careful optimism and highlight the need for time and awareness-building efforts. The mention of being "*new to the industry*" suggests a recognition of the technology's novelty, emphasizing the importance of education within the financial sector. It also reflects a conservative approach or a lack of detailed information in this emerging domain.

4.3.7 Environmental Impact & Sustainability

Bankers and Financial Institutions see potential environmental benefits in terms of cost efficiency and reduced material wastage. One respondent highlights the advantage of low material wastage and a cleaner construction process, stating, *"Material wastage would be low, and we can also develop a way without much dust."* However, there is limited discussion on sustainability-related concerns, which suggests a need for increased awareness or detailed information within this stakeholder group.

4.3.8 Future Outlook

Bankers and financial Institutions seem to have a reserved stance, possibly due to a lack of detailed information or involvement in the technical aspects of 3D concrete printing. The emphasis on cost-cutting aligns with their financial perspective, indicating a desire for advancements that offer economic benefits. The willingness to receive and share information suggests an openness to learning and collaboration.

These responses reflect the need for more engagement and information-sharing between the 3D concrete printing industry and financial stakeholders to address any reservations and promote a better understanding of the technology.

4.4 Academia and Research

The academia and research fraternity play a pivotal role in shaping the construction sector by influencing architects, builders, contractors, and consumers. Through research findings and educational initiatives, academia can promote disruptive and innovative technologies, sustainable construction practices, and advanced design methodologies. Furthermore, academic insights empower consumers with information on modern construction methods, materials, and environmentally friendly options, encouraging informed choices. This dynamic interaction between academia and industry stakeholders ensures a progressive and well-informed construction landscape.

4.4.1 Knowledge and Awareness

Academia and Research stakeholders demonstrate diverse awareness levels regarding 3D concrete printing. Some express an intermediate or basic understanding with statements like "I have gone through this technology very recently" and "I simply know the technique of 3D

printing." Others admit to not yet encountering the technology directly, stating, "Not yet searching opportunities for the same." Project references, including the India Post Office in Bangalore and construction at IIT Madras, indicate varying degrees of exposure.
Quotes such as "No, I just know that it exists" and "Recently, India Post office in Bangalore was created completely as 3D print" reflect differing levels of direct engagement. The responses collectively showcase a spectrum of awareness, ranging from those actively exploring the technology to those yet to delve into its intricacies.

4.4.2 Perceived benefits

Academia and Research stakeholders exhibit an optimistic view regarding the perceived benefits of 3D concrete printing in housing construction. Emphasizing speed and efficiency, respondents note "faster delivery of projects" and a construction time around "1/4 of traditional techniques." The recurring theme of cost-effectiveness is nuanced, with expectations of being "cheaper in the longer run" despite acknowledging initial high costs. Sustainability emerges as a significant benefit, with mentions of being a "sustainable technology" and "flexible and sustainable." Respondents appreciate the flexibility in design, iterative decision-making, and the ability to print any desired shape, aligning with the perception that 3D printing allows for "innovative designs." Reduction in labor dependency is highlighted, with phrases like "minimal labor force requirement" and "man-hours and associated labor costs will be lower." Continuous operation, working 24x7 without limitations, is seen as a distinctive advantage. Material homogeneity is considered beneficial for quality and durability, contributing to the perception that 3D printing provides "homogeneous mixtures." The potential for "efficient" and "very fast" processes enhances the overall positive view. While acknowledging challenges, such as initial high costs and the need for advancements, academia, and research stakeholders envision 3D concrete printing as a transformative force in construction, offering accelerated, cost-effective, and sustainable solutions with innovative design possibilities.

4.4.3 Perceived Challenges

Academia and research stakeholders offer a nuanced perspective on challenges in adopting 3D concrete printing for housing construction. Construction complexities, including bonding difficulties and extended construction times, are recurrent themes. Respondents highlight the pivotal role of heavy setups, demanding "highly skilled workmanship and heavy logistics," reflecting concerns about operational demands. Technical challenges extend to the variety of printing materials, where one participant notes, "a variety of 3D printing materials," showcasing the need for standardization and compatibility. Uncertainties persist regarding material engineering, with participants expressing reservations about the longevity and structural soundness, exemplified by the comment, "no longitudinal study available to convince about the longevity of the solution." Regulatory considerations emerge, with a call for incorporating safety standards and a comprehensive regulatory framework. Transportation logistics, both for setup and equipment movement, are underscored as significant barriers, as reflected in the quote, "maybe to transport the equipment to the desired location." The collective perspective emphasizes the imperative to address technical intricacies, regulatory frameworks, logistical challenges, and material concerns to ensure the successful and sustainable integration of 3D concrete printing in housing construction.

4.4.4 Quality and Durability

The majority of responses from the academia and research categories reflect a cautiously optimistic outlook on the quality and durability of 3D-printed concrete structures compared to traditional construction methods. *"3D printed structures are better than traditional."* This positive view indicates a favorable stance on quality. *Another respondent emphasizes, "With technological advancements, it will improve,"* suggesting a positive trajectory for both quality and durability in the future.

However, it's essential to note that there are also reservations and uncertainties expressed by some respondents. One respondent acknowledges the need for further advanced material research, stating, "There is a further scope for advanced material research for 3D printing," highlighting the ongoing pursuit of enhancing both quality and durability.

A few participants expressed reservations about durability, with one respondent stating uncertainty, "No idea," *and another suggesting the possibility of less durability,* "Maybe less durable."*

In summary, while the majority expresses optimism, acknowledging the potential for improvement and advantages, there are a few that raise concerns, highlighting the importance of continued research and advancements in materials to address potential challenges related to durability in 3D-printed concrete structures.

4.4.5 Stakeholder Involvement & Skilling needs

Academia and research responses reveal a positive outlook on the impact of 3D concrete printing on the roles of stakeholders. The consensus suggests that the technology streamlines tasks, allowing for more precision and efficiency. One of the respondents noted, "*It makes the job easier in terms of achieving the desired shape with more precision.*" Additionally, there is acknowledgment of a shift in expertise towards equipment and software, with another respondent stating, "*It is shifting from core technical expertise to equipment and software expertise*." This collective sentiment aligns with the belief that architects, engineers, and contractors will experience a reduced workload, benefiting from the innovative approach.

Regarding skilling needs, there is unanimous agreement on the necessity for new skill sets. The consensus emphasizes the importance of initial training. One of the respondents highlights, "*Initial training is essential,*" reinforcing the view that a foundational understanding is crucial. The sentiment underscores the requirement for comprehensive training programs to navigate the complexities of the technology. Another respondent notes, "*Yes, 3D concrete printing is a new technology that requires training in terms of benefits, uses, dos & don'ts, pros & cons, design implementation,*" highlighting the multifaceted nature of the required skill sets.

4.4.6 Market Adoption, Acceptance & Barrier

Amongst Academia and the Research community, there is a positive perception of 3D concrete printing technology. Respondents see it as a technology that is just starting to be accepted, with the potential for significant evolution in the future. The sentiment is optimistic, as one respondent notes, *"Its future is bright."* However, there is a recognition that the technology is still in its early stages, and widespread adoption may take time.

In terms of barriers, awareness, adaptation, and the traditional mindset are considered hurdles. As one respondent states, *"Adaptation of technology [is] a little difficult because of the traditional mindset of Indians."* Skilled manpower and technological awareness are seen as crucial factors. There is also an acknowledgment that capital requirements and government support play a significant role in overcoming barriers. This suggests that while there is optimism about the future potential of 3D concrete printing, overcoming current barriers requires a multifaceted approach involving skill development, awareness campaigns, and support from various stakeholders, especially the government.

4.4.7 Environmental Impact & Sustainability

Researchers and academic stakeholders envision 3D concrete printing as a promising avenue for reducing environmental impact and enhancing sustainability in housing construction. The consensus emphasizes the technology's capacity to curtail material wastage, a key environmental concern in traditional construction. The quote *"Benefits: reduce wastage; Drawbacks: High initial cost"* encapsulates the recognition of environmental advantages coupled with an acknowledgment of financial challenges. Furthermore, the limitation on traditional material use is viewed as an opportunity for exploring more sustainable alternatives, prompting the call for ongoing research into the environmental impact of modern materials.

This aligns with the sentiment expressed: *"The uses of traditional material become limited in 3D printed concrete. However, the environmental impact of utilizing modern material in 3D concrete is a subject of research."* Sustainability considerations are underscored, with stakeholders highlighting the eco-friendly nature of 3D concrete printing and its potential to control physical and natural factors for more sustainable outcomes. The diversity in 3D printing materials, spanning thermoplastics, metals, resins, and ceramics, is seen as a positive step towards reducing emissions and material wastage. *"The volume of construction material used in 3D concrete is small as compared to traditional construction. However, we can control various physical natural factors like sunlight and temperature management,"* reflects a holistic perspective, where reduced material usage aligns with sustainability goals. While optimism is evident, researchers also acknowledge the need for continued investigation and research to fully understand and optimize the environmental benefits of 3D concrete printing, providing a nuanced and academically grounded perspective.

4.4.8 Future Outlook

Academia and research stakeholders envision a positive future for 3D concrete printing, emphasizing affordability, faster construction, and optimization of techniques for wider adoption. *"It offers affordable and faster construction,"* highlighting the potential economic benefits. However, concerns about the time it might take for adoption in diverse markets like India suggest a nuanced understanding of regional challenges.

Their desire for material advancements, especially the use of green materials, demonstrates a commitment to sustainable practices. *"Utilization of green material in the concrete printing process"* signifies a keen interest in environmentally friendly construction techniques. The acknowledgment of various 3D printing materials, including thermoplastics, metals, resins, and ceramics, showcases a multifaceted approach to technology.

The stakeholders expressed a need for research on the integration of traditional construction elements like iron rods in 3D printing, indicating a realistic approach to the technology's implementation. *"Houses usually have iron rods reinforced in between concrete, especially in roofs; how that will take place is something to think about."* This suggests a critical evaluation of the compatibility of 3D printing with existing construction norms.

Their recommendations for further research emphasize sustainable material exploration, tool and equipment optimization, and the importance of government regulations overseeing this technology. *"In my opinion, first of all, we have to work out sustainable material for 3D printing. Secondly tools and equipment should be optimized. What regulations the government* *is trying to bring to oversee this technology?"* This collective perspective showcases a commitment to advancing 3D concrete printing technology with a nuanced understanding of materials, sustainability, and regulatory considerations.

Chapter 5: The Way Forward

5.1 Observations and Conclusion

The following observation emerged from the study of the literature and primary data collected from stakeholders, as well as insights from the evolution of 3D concrete printing (3DCP), which provides a way forward and guides future directions in the field.

Based on the analysis of the literature and stakeholder perspectives, we gain a holistic understanding of the current state and advancements in 3DCP technology within the construction industry.

5.1.1 Knowledge and Awareness

In the realm of Knowledge and Awareness regarding 3D Concrete Printing (3DCP), scholarly literature indicates that 3DCP represents an emerging and novel technology, necessitating training initiatives for workers on its proficient utilization. Additionally, there exists a requirement to engage individuals who are well-versed in this technology. The challenge intensifies in remote communities where literacy and numeracy pose significant obstacles (Kral, 2009). Noteworthy observations from studies highlight a concurrent rise in labor productivity; however, a deficiency in understanding new technology has been identified as a contributing factor to diminishing labor productivity (T., 2015). Not only lack of knowledge but lack of implementation of this technology is also a reason for the downfall. (García de Soto B, 2018).

Whereas Consumer awareness of 3D printing in construction varies, with some showing limited familiarity. Media representation plays a significant role in shaping their knowledge. Builders and Contractors in the Housing Sector exhibit diverse understanding levels, recognizing 3D printing as an advanced technology with potential benefits like material wastage reduction and geometric freedom. Their familiarity ranges from basic to moderate, often acquired through online sources. Bankers and financial institutions, having a more peripheral understanding, express a need for more information about 3D concrete printing. Academia and Research stakeholders display varied awareness levels, with some having an intermediate understanding and others admitting to limited direct encounters with the technology.

In conclusion, the landscape of knowledge and awareness surrounding 3D Concrete Printing (3DCP) presents a multifaceted scenario

In the pursuit of mainstreaming 3DCP, bridging these knowledge gaps becomes imperative, necessitating targeted educational efforts and broader dissemination of information across all stakeholder groups

5.1.2 Perceived Benefits

In terms of perceived benefits, the literature highlights the growing significance of 3D Concrete Printing (3DCP) in the housing sector, considering it a strategic challenge and an alternative building technology (Prachi Mehar*, 2020). Identified as a progressive technology, 3DCP is poised to revolutionize the construction industry (Das, 2022). Noteworthy is the efficiency of Additive Manufacturing (AM) in generating parts from a CAD model, presenting notable time and cost savings, particularly for prototypes (Gibson I, 2015). The advantages extend to sustainability, as 3D printing contributes to eco-friendly structure creation and reduces pollution compared to traditional construction methods (P. Wu J. W., 2016). 3DCP offers promises of accelerated and enhanced construction, environmental friendliness, lower labor costs, geometric flexibility, and heightened overall productivity (S. Manjikian, 2020). Moreover, the economic feasibility of houses constructed using 3D printers is underscored (Abhishek Pandit1, 2021). Additionally, 3D printing addresses weather-related work stoppages and streamlines the process of designing and manufacturing intricate components (Pegna, 1997; Han, 2003).

In terms of perceived benefits, consumers express enthusiasm about the transformative potential of 3D printing, anticipating benefits in cost, efficiency, and sustainability despite a few challenges. Builders and Contractors foresee cost reductions, time efficiency, operational streamlining, material conservation, precise design capabilities, and enhanced coordination, emphasizing the transformative potential in addressing labor, time, and cost issues. Bankers and Financial Institutions envision "low-cost benefits" but acknowledge challenges in deploying 3D printers for large-scale towers. They express concerns about time efficiency while maintaining a positive outlook with "good future prospects." Academia and Research stakeholders are optimistic about the speed, efficiency, sustainability, and cost-effectiveness of 3D printing. They highlight flexibility in design, reduced labor dependency, continuous operation, material homogeneity, and the potential for "efficient" and "very fast" processes, viewing 3D printing as a disruptive and transformative force in the housing sector

In conclusion, the academic discourse on 3D Concrete Printing (3DCP) underscores its growing significance in housing, portraying it as a strategic challenge and an alternative building technology (Prachi Mehar*, 2020). Recognized as a progressive force, 3DCP stands poised to revolutionize the construction industry, offering efficiency in generating parts through Additive Manufacturing (AM), leading to notable time and cost savings, particularly for prototypes (Gibson I, 2015). Sustainability emerged as a crucial aspect, contributing to eco-friendly structures and reducing pollution compared to traditional methods (P. Wu J. W., 2016). The promises of accelerated construction, environmental friendliness, reduced labor costs, geometric flexibility, and heightened overall productivity mark 3DCP as transformative (S. Manjikian, 2020). The economic feasibility of houses constructed using 3D printers is emphasized (Abhishek Pandit1, 2021). Stakeholders, including consumers, builders, bankers, and academia, express optimism, foreseeing benefits in cost-effectiveness, efficiency, and sustainability. Despite acknowledged challenges, the transformative potential of 3DCP in reshaping the housing sector is evident, offering a glimpse into a future where innovative, sustainable, and efficient construction practices take center stage.

Based on the above observations, it can be concluded that 3D Concrete Printing (3DCP) holds significant promise and potential in transforming the housing and construction sector. This suggests a growing acceptance and interest in adopting 3DCP for its potential to address key issues in the construction industry and usher in innovative, sustainable, and efficient building practices.

5.1.3 Perceived Challenges

Although the literature showcases numerous benefits of 3DCP adoption, many challenges continue to exist. The introduction of 3DCP printing may impact the existing construction workforce, potentially reducing the number of required employees, presenting both cost-cutting benefits and challenges for skilled workers (Kutay, 2023) Design and material limitations hinder meeting user expectations, especially in large-scale projects, highlighting current unsuitability for such endeavours (Kutay, 2023). Economic complexities emerge with the initial high cost and transportation challenges associated with the implementation of 3D printing equipment (Kutay, 2023). Introducing 3D printing necessitates worker training, posing challenges, particularly in remote areas with literacy issues (Kral, 2009). The energy consumption is a significant concern, with research suggesting 3D printers may use 100 times more electrical energy than conventional methods (Abhishek Pandit1, 2021). The lack of knowledge and implementation of 3DCP technology contributes to challenges, impacting overall productivity (García de Soto B, 2018).

From stakeholders' perspective, Consumers express concerns about the perceived high cost of 3D concrete printing compared to traditional methods. Acceptance challenges exist, particularly in rural areas where skepticism about the technology's quality persists. Addressing regulatory and technical issues, including standards, is crucial for widespread acceptance. Concerns among builders and contractors encompass structural integrity, seamless integration of 3D-printed parts, and the durability of structures. Feasibility issues arise for multi-floor construction, along with challenges in awareness, public adoption, and potential job loss due to automation.

Banks and Financial stakeholders raise reservations about public acceptance, citing the novelty of 3D concrete printing. Concerns include time-consuming large-scale printing, high setup costs, and the need for regulatory approvals. Strategic emphasis is placed on raising awareness about the technology's pros and cons. Academicians and Researchers emphasize challenges related to heavy setups, skilled manpower, and logistical demands. Technical concerns include material variety, necessitating.

In conclusion, while scholarly literature extols the benefits of 3D Concrete Printing (3DCP), challenges persist. 3DCP's introduction may impact the construction workforce, providing cost-cutting benefits but raising concerns for skilled workers (Kutay, 2023). Design and material limitations hinder large-scale projects, indicating the current unsuitability of 3D printing (Kutay, 2023). Economic complexities arise from high initial costs and transportation challenges (Kutay, 2023). Introducing 3D printing necessitates worker training and poses challenges, particularly in remote areas (Kral, 2009). Energy consumption is significant, with 3D printers possibly using 100 times more electrical energy than conventional methods (Abhishek Pandit1, 2021). Lack of knowledge and implementation hinders productivity (García de Soto B, 2018). Consumers cite concerns about 3DCP costs and acceptance, particularly in rural areas. Builders express worries about structural integrity, awareness, and potential job loss. Banks raise reservations about public acceptance and regulatory challenges. Academicians highlight technical and logistical concerns, necessitating comprehensive regulations and standards for wider adoption.

5.1.4 Quality and Durability

Literature states that the Current technological limitations in design and materials may lead to 3D-printed structures falling short of end users' expectations, especially in large-scale projects (Kutay, 2023).

While Consumers express optimism,some also express skepticism, emphasizing the need to address doubts through awareness building. Builders' perspectives on the quality and durability of 3D-printed structures vary, with some anticipating improvements while others prefer traditional methods. Optimistic builders cite enhanced planning capabilities but also raise concerns about adaptability to specific climates and finish quality. Bankers recognize 3D printing as an upgraded technology but express reservations about achieving the desired quality and finish. Academia holds a cautiously optimistic view, with a few raised concerns and emphasizing the importance of ongoing research to address potential challenges in the durability of 3D-printed concrete structures. Overall, varied perspectives underscore the need for further exploration and understanding of quality expectations in adopting 3D printing technology.

To conclude, the literature notes 3D printing's current technological limits and potential shortfalls in large projects (Kutay, 2023). While consumers are optimistic, skepticism calls for increasing awareness efforts by the Government and Regulators. Builders hold diverse views on 3D-printed concrete, facing concerns about quality and durability. Bankers see 3D printing as an upgrade but express aesthetic reservations. Academia is cautiously optimistic, urging ongoing research for material advancements. Overall, recommendations include collaborative awareness and continued research to address concerns, fostering 3D printing adoption in construction.

5.1.5 Stakeholder Involvement & Skilling Needs

According to the literature, the integration of 3D printing presents a societal challenge by diminishing the need for conventional construction positions, affecting skilled workers involved in tasks like concrete pouring and steel rebar installation (Kutay, 2023). Additionally, the incorporation of 3D printing technology requires extensive training for the workforce, emphasizing the recruitment of individuals familiar with this innovation. The challenges of training initiatives are accentuated in remote communities where significant literacy and numeracy obstacles exist (Kral, 2009).

From a stakeholders' involvement and skilling perspective, consumers foresee potential shifts in traditional roles due to 3D printing, emphasizing the need for new skill sets and training programs. There's consensus amongst Builders, architects, and engineers that remain essential, but demand for traditional contractors and laborers might decrease. The positive outlook aligns with a willingness to adapt and embrace advancements. Banking and Financial Institutions recognize the demand for updated expertise, highlighting the importance of skill development. Academia and the research community anticipate streamlined tasks and acknowledge a shift in expertise toward equipment and software. There's unanimous agreement on the necessity for new skill sets, emphasizing the importance of initial training to navigate the complexities of

3D printing technology. Overall, stakeholders express openness to embracing new skills and training for the transformative changes brought about by 3D printing.

The integration of 3D printing in construction poses a societal challenge by impacting traditional roles, particularly skilled workers involved in concrete pouring and steel rebar installation. Training initiatives face heightened challenges in remote communities due to literacy and numeracy obstacles. However, stakeholders across various sectors exhibit a generally positive outlook, recognizing the transformative potential of 3D printing.

To conclude, a strategic approach involving training, awareness, collaboration, and research will enhance the successful integration of 3D printing in construction while addressing the challenges and concerns highlighted by stakeholders.

5.1.6 Market Adoption, Acceptance, and Barriers

Several barriers impede the widespread adoption and acceptance of 3D Concrete Printing (3DCP) in the construction industry. The introduction of 3D printing brings forth a societal challenge, potentially diminishing the demand for traditional construction roles such as concrete pouring and steel rebar installation, affecting skilled workers despite the promised cost-cutting benefits (Kutay, 2023). Furthermore, limitations in the design and materials of 3D-printed structures, especially in large-scale projects, present obstacles to meeting end-user expectations (Kutay, 2023). Economic intricacies arise from the initial high cost and transportation complexities associated with 3D printing equipment, while the restricted availability of suitable materials complicates compatibility (Kutay, 2023). Notably, 3D printers demonstrate significantly higher energy consumption, raising environmental concerns (Abhishek Pandit1, 2021). Additional challenges involve the unsuitability of existing automated fabrication technologies for large-scale products, incongruence with conventional design approaches, material limitations for automated systems, and the economic unattractiveness of costly automated equipment (Skitmore, 2015).

Stakeholders hold varying views on the market adoption and acceptance of 3D Concrete Printing (3DCP). Consumers express optimism but cite concerns about regulatory hurdles, economic considerations, and logistical challenges. Builders and contractors are cautiously optimistic, linking acceptance to technological progress, standardization, and government initiatives. Identified barriers encompass government support, regulatory concerns, lack of skilled professionals, and high initial costs. Bankers are cautious, expecting gradual acceptance and emphasizing the need for time and awareness-building. The academia and research community is positive about 3DCP's future but recognizes barriers related to awareness, a traditional mindset, skill development, and government support. Overcoming these hurdles requires a multifaceted approach involving skill development, awareness campaigns, and government support.

In summary, the integration of 3D Concrete Printing (3DCP) faces multifaceted challenges outlined in the scholarly literature (Kutay, 2023; Abhishek Pandit1, 2021; Skitmore, 2015). These challenges encompass societal impacts on traditional construction roles, design limitations affecting end-user expectations, economic intricacies associated with high costs and material compatibility, and environmental concerns due to increased energy consumption. Stakeholder perspectives, as highlighted in various studies, reflect a mix of optimism and caution (Kutay, 2023). Consumers express optimism tempered by concerns about regulatory hurdles, economic considerations, and logistical challenges. Builders and contractors exhibit cautious optimism, linking acceptance to technological progress, standardization, and government initiatives. Bankers, taking a cautious stance, anticipate gradual acceptance and emphasize the need for time and awareness-building (Kutay, 2023). Academia and research stakeholders express positivity about 3DCP's future but acknowledge barriers related to awareness, a traditional mindset, skill development, and government support. Recommendations based on these observations include targeted awareness campaigns, technological advancements, government initiatives, comprehensive training programs, fostering collaboration among stakeholders, and incentivizing innovation.

The overarching recommendation emphasizes a collaborative and adaptive approach involving stakeholders, industry players, and policymakers to navigate the evolving landscape of 3DCP adoption in the construction industry.

5.1.7 Environmental Impact & Sustainability

Few studies state that 3D printing stands out as a valuable contributor to sustainability in construction, enabling the creation of eco-friendly structures and mitigating pollution, a notable departure from conventional construction practices (P. Wu J. W.,2016). Moreover, the adoption of 3D printing technology presents a promising avenue to combat the significant carbon emissions associated with the construction industry, leading to a reduction in energy consumption and minimizing water wastage (Abhishek Pandit1, 2021). However, it is noteworthy that this eco-friendly approach is accompanied by increased energy consumption, with research suggesting that 3D printers utilize approximately 100 times more electrical energy than traditional methods (Abhishek Pandit1, 2021). This highlights the importance of a balanced understanding of the environmental impact and energy dynamics associated with integrating 3D printing into construction practices.

Data analysis and interactions regarding Environmental Impact & Sustainability highlight that consumers cautiously embrace the potential cost reduction and efficiency gains associated with 3D concrete printing, highlighting positive aspects such as reduced material waste and enhanced efficiency. Builders and contractors express optimism about environmental benefits but voice concerns about sustainability, citing issues like the inability to use local materials, significant power requirements, and limitations in sustainability practices. While many consumers and builders are confident in the positive environmental impact, it's crucial to address concerns raised by some stakeholders, emphasizing the need to overcome technological and material limitations for enhanced sustainability in 3D concrete printing. Bankers and Financial Institutions recognize potential environmental benefits but suggest a lack of detailed discussions on sustainability-related concerns, indicating a need for increased awareness. Researchers and academic stakeholders view 3D concrete printing as a promising avenue for environmental impact reduction, emphasizing material wastage control. The diversity in printing materials is seen positively, aligning with sustainability goals, but stakeholders acknowledge the need for continued research to optimize environmental benefits. It can be concluded that 3D printing in construction contributes to sustainability by enabling eco-friendly structures and reducing pollution (P. Wu J. W., 2016). The adoption of 3D printing shows promise in lowering carbon emissions and minimizing energy and water use (Abhishek Pandit1, 2021). However, the eco-friendly approach comes with significantly higher energy consumption (Abhishek Pandit1, 2021). Stakeholders, including consumers, builders, and researchers, express optimism about environmental benefits but highlight concerns about sustainability, emphasizing the need to overcome technological and material limitations for enhanced sustainability in 3D concrete printing (P. Wu J. W., 2016; Abhishek Pandit1, 2021). Awareness and continued research are crucial for optimizing environmental benefits and addressing stakeholders'

5.1.8 Future Outlook

Academic literature states that the construction industry, which is acknowledged as one of the world's largest, is actively seeking avenues to enhance productivity (Gerbert P, 2021; Maskuriy R, 2019). While labor productivity initially saw an increase, recent studies suggest a decline attributed to a lack of knowledge about emerging technologies (T., 2015). Notably, 3D printing technology has garnered attention in the housing industry and is seen as a strategic challenge and a potential replacement for traditional building methods (Prachi Mehar*, 2020). The evolving technology of 3D concrete printing (3DCP) holds significant promise for revolutionizing the construction sector, representing a noteworthy development in the industry's technological landscape (Das, 2022).

Stakeholders hold varying perspectives on the future outlook of 3D concrete printing (3DCP) in the construction industry. Consumers express optimism about its potential impact, foreseeing cost reduction and faster construction. Builders and contractors are cautious yet optimistic, anticipating high or moderate acceptance levels but acknowledging the need for technological progress and awareness. Bankers and financial institutions take a cautious stance, emphasizing the need for time and awareness-building efforts for wider adoption. Academia and research stakeholders are positive about 3DCP's future, envisioning significant evolution but recognizing the technology is still in its early stages. Despite the optimism, barriers such as government support, regulatory concerns, lack of skilled professionals, and high initial costs are identified, indicating the need for a multifaceted approach involving skill development, awareness campaigns, and government support to overcome these challenges to fully realize the potential of 3DCP in construction.

The academic literature underscores the construction industry's proactive pursuit of increased productivity, with a focus on emerging technologies. Despite an initial rise in labor productivity, recent studies highlight a decline attributed to a lack of knowledge about these technologies. Noteworthy among them is 3D printing technology, which is gaining attention in the housing industry as a strategic challenge and a potential replacement for traditional building methods. The evolving technology of 3D concrete printing (3DCP) is deemed promising for revolutionizing the construction sector. Stakeholders' perspectives on the future outlook of 3DCP vary, with consumers expressing optimism, builders, and contractors being cautiously optimistic, and bankers adopting a more cautious stance. Academia and research stakeholders foresee significant evolution but acknowledge the technology is in its early stages. Barriers, including government support, regulatory concerns, a shortage of skilled professionals, and high initial costs, present challenges that necessitate a comprehensive approach involving skill development, awareness campaigns, and government support for the full realization of 3DCP's potential in construction.

5.2. Recommendations

Based on the review of academic literature, Study of the Evolution of 3DCP, and perceptions of various stakeholders, the 3DCP technology appears to have a transformational impact on the Housing Construction Sector in the Indian context.

To improve the adoption of 3DCP technology and alleviate some of the perceptions among stakeholders, various interventions are proposed for Governments' consideration.

The following interventions are recommended:

1. To integrate 3DCP into mainstream construction in the housing sector, it is essential to address knowledge gaps among stakeholders. This requires focused awareness programs and the dissemination of information through various channels highlighting the benefits and potential of 3D concrete printing in housing construction.
2. The government should establish Centers of Excellence (CoE) dedicated to different aspects of a Public-Private Partnership (PPP) model involving academia and industry; this collaborative approach aims to foster research and development in 3DCP for construction in the housing sector. The focus of CoE's can be the dissemination of Knowledge, promotion of 3DCP in the Housing Sector, Sustainability practices, Research in Building materials for 3DCP, etc
3. In order to foster trust regarding Safety and encourage wider acceptance, the government should publish rules, regulations, standards, and guidelines for 3D concrete printing (3DCP) in the housing sector.
4. The government should establish quality assurance standards and certifications for 3D concrete printing technology to ensure the reliability and safety of printed housing units.
5. The government should allocate funds for constructing model projects designed for demonstration purposes (and run their operations from these facilities). These projects can serve as showcases, illustrating the effectiveness and reliability of 3D concrete printing technology in housing construction. This initiative aims to address consumer concerns regarding slow acceptance and the early stages of adoption.
6. Governments should offer subsidies, financial incentives, and preferential loan terms to architects, builders, and contractors, adopting sustainable and innovative practices and encouraging the adoption of 3D concrete printing technology.
7. The government should encourage eco-friendly practices in the housing sector and provide accessible loans and mortgage solutions for eco-friendly and technologically advanced homes, encouraging the adoption of sustainable practices by consumers.

8. Government should Implement initiatives to make 3D-printed housing units more accessible and affordable for a wider range of consumers, addressing concerns related to high initial costs.
9. To reduce skill gaps, governments should encourage academic institutions to design courses in 3DCP and train students in the emerging contexts of 3DCP. Academic institutions should also conduct research on social, technological, engineering, and management aspects of 3 DCP.
10. Develop and implement comprehensive training programs for the workforce, addressing the social challenges posed by the introduction of 3D printing technology. This initiative will contribute to a smoother transition, mitigate job displacement concerns, and foster a skilled workforce capable of harnessing the technology's full potential. These programs should focus on equipping individuals with the skills required for the evolving 3DCP landscape.

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