**Potential advantages and creative opportunities opened by 3D Printing technology in housing construction**

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**Abstract**

3D Printing, a form of fabrication technology has become increasingly popular in recent years and is being used for various applications, including sustainable, low-cost, and highly customizable housing. This paper examines the potential advantages such as reduced construction time and waste, greater efficiency in terms of time, money, and materials opened by 3D printing technology and the environmental benefits of using this technology in housing construction. In addition, it highlights how 3D printing technology can open up new opportunities for creativity and innovation in the housing construction sector, allowing for more unique and personalized homes and the potential for using 3D Printing to create unique housing designs. Finally, the paper explores the barriers that need to be addressed for 3D Printing to become a viable option for housing construction, the potential of 3D printing technology to revolutionize the way we build homes, and the implications of this technology for the future of housing construction.

**Keywords**: Creativity, Housing Solutions, Innovation, Procurement Systems, Regulations

**Introduction**

A significant number of people in Nigeria are homeless and live in sub-standard and unaffordable housing. Housing is a basic human need fundamental to economic and social well-being; however, housing inadequacy remains despite efforts and policies of governments (Baker, 2004). The need to provide housing forms one of the critical challenges facing developing countries, especially since it is regarded as a basic need that forms one of the critical human rights (Kotane, 2016). Given the growing population, delivering quality and sustainable houses to meet the required supply is a global problem challenging both developed and developing countries (Adebayo, 2011). To address these challenges, construction professionals have begun looking at innovative solutions, such as 3D printing technology, to increase the industry's performance (Khazemian and Khoshnevis, 2021).

According to Ashraf et al. (2018), three-dimensional (3D) Printing, also known as Additive Manufacturing (AM), is an advanced manufacturing process that automatically produces complex geometric shapes from a 3D computer-aided design model. It is originally developed as an automated method of producing prototypes (Manners-Bell and Lyon, 2012). It is referred to as an 'additive' process because each layer is 'printed' until a three-dimensional product is created. Additive fabrication technology, which involves printing layer by layer using different materials and methods such as thermoplastics, glue and metal powder. The traditional 'reductive' manufacturing techniques in which materials are removed are a more protracted and more expensive process (Manners-Bell and Lyon, 2012). According to Manners-Bell and Lyon (2012), 3D-printed products can be printed for review by the designer or engineers and revisions printed equally with the same level of ease. Furthermore, the items produced are original or perfect copies. All 3-D printers use 3D CAD software that measures thousands of cross-sections of each product to determine exactly how each layer will be constructed (Berman, 2012).

Additionally, 3D printing technology has been applied to many diverse fields of industries such as aerospace, automobile and biomedical engineering due to its significant advantages in creating functional parts efficiently and effectively (Ashraf et al., 2018). There is currently accessible, downloadable software from online repositories of this technology, largely due to expanding applications and decreased costs. As the interest in 3D Printing grows, potential large-scale applications are emerging in the construction industry. According to Wu et al. (2016), there have been many attempts in the construction industry to use 3D Printing to increase customization, reduce construction time, and improve affordability.

Research relating to the application of 3D Printing in the construction industry is still in its infancy. However, numerous new experiments have been conducted in the construction industry, such as the Apis Cor House in Russia and the Office of the Future in Dubai, to explore the full potential that 3D Printing can bring to the construction industry (Sakin and Kiroglu, 2017). However, these experiments are very fragmented, and the use of 3D Printing in housing construction is limited. Therefore, this paper examines the advantages, creative opportunities, and barriers to implementing 3D Printing in housing construction. This study uses a comprehensive literature review to achieve the study objectives.

**3D Printing in Construction**

3D Printing of buildings and building components as the future of sustainable construction has become one of the fastest-growing technologies. Its presence is evident in everyday life, and printers are commonly used in all industries. The open-source systems, prototyping of new products and innovative applications has caused a lot of achievements in medicine, automotive, aerospace and construction industry. One of the primary uses for 3D Printing in construction is creating mockups for building components. These mockups are created by the Virtual Design and Construction team, which in turn facilitates accessible communication between the parties involved in the project and saves time and money by eliminating long lead time from third-party mockups (Kidwell, 2017).

According to Kidwell (2017), the prefabrication of full-scale building components, such as interior walls and partitions, are areas in which 3D Printing is being utilized on a larger scale in construction. Kidwell (2017) notes that a Tennessee-based company called Branch Technology is a leading innovator in the field of 3D Printing, using their patented "Cellular Fabrication" (C-Fab) method to prefabricate interior walls and partitions. A French Company, XtreeE, is another leader in 3D Printing for construction components. This company specializes in concrete Printing and has used this technology to print stormwater drains that are prefabricated in a warehouse in only 9 hours and assembled on-site (Kidwell, 2017). However, other companies, such as World Advanced Savings Project (WASP), an Italian Company, are taking a more eco-friendly approach as they aim to provide inexpensive and environmentally friendly housing for low-income developing nations by using locally sourced clay, straw, lime and sand to produce simple cylindrical shelters (Kidwell, 2017).

Contour Crafting (CC) is another concrete printing method that can be used in fabricating complex structures and adapting to sophisticated designs, which currently available automated systems cannot do. This method uses robotics to construct objects layer by layer and is most commonly used for small-scale industrial designs. The key feature of Contour Crafting is the use of trowels attached to the nozzle. This method was identified as the only one capable of delivering components large enough to build structures. It is suitable for rapidly fabricating large-scale complex-shaped objects with a smooth surface finish. The Contour Crafting process is based on an extrusion and filling process. This method has been the focus of intensive research at the USC rapid prototyping laboratory. Rapid advances in Contour Crafting will be critical if it is considered a viable option for construction automation.

The construction of 3D-printed structures and building components is gradually gaining global recognition, and the first house was printed in 2014, starting a new chapter in building technology. The immediate availability of industry-standard materials used in Contour Crafting makes it easy for it to be used for full-scale housing construction (Hwang and Khoshnevis, 2005; Khoshnevis et al., 2006).

**Advantages of the Use of 3D Printing Technology in Housing Construction**

According to Masera et al. (2017), the six main areas where 3D printing present many potential advantages over traditional technologies are flexible designs of complex shapes; using multiple environmentally friendly materials; removing the need for formwork systems or moulds; reduced transport and installation costs; optimized use of materials (placed only where necessary for structural or functional reasons); and no waste production. Others are labour efficiency, time and cost savings, and reduced environmental impacts (Kidwell, 2017; Wu et al., 2016). The high demand for construction projects in recent years has increased the demand for skilled and unskilled labour. 3D Printing eliminates the need for large crews to produce components such as concrete walls because these are manufactured offsite in a factory. The cost of materials and labour alone can be reduced by up to 80% when using 3D printing technology. The time taken to complete a 3D-printed building is significantly reduced; for example, with 3D-printed prefabricated structural components, a crew of 18 labourers was able to assemble an office building in just 17 days.

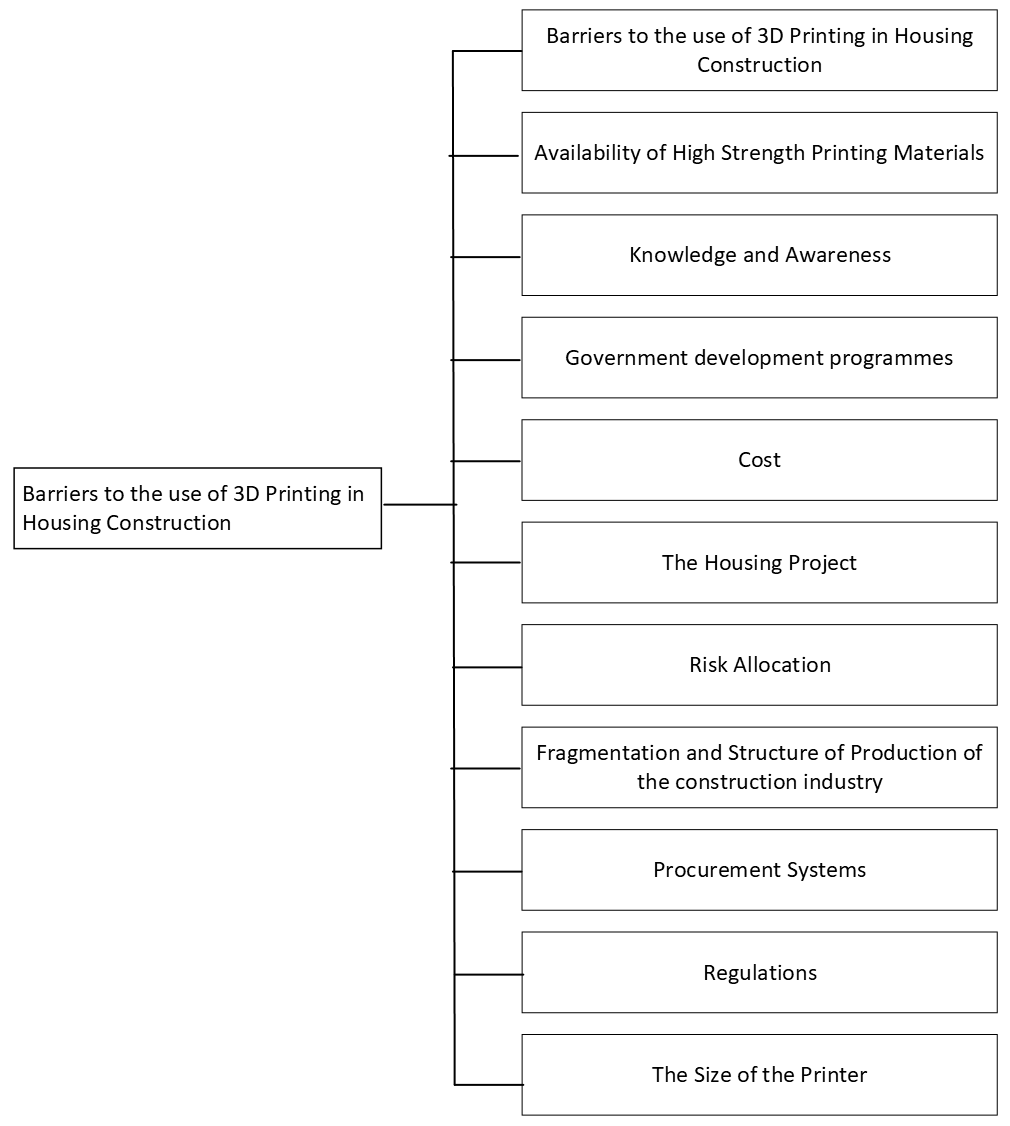
Furthermore, 3DP companies, like Winsun and WASP, use inexpensive and sustainable materials that utilize construction waste or locally sourced clay and straw to produce 3D-printed buildings. This, in turn, saves 30-60% of the materials used. Additionally, 3D Printing can create irregular and exotic contours that are difficult to achieve using traditional methods allowing architects to design complex components without additional costs (Kidwell, 2017; Wu et al., 2016).

**Opportunities for creativity and innovation in the housing construction sector opened up by 3D Printing Technologies.**

Masera et al. (2017) noted that the increasing diffusion of 3D printers in architecture and engineering offices is already affecting the design process, allowing for the immediate realization of sketch models directly from concept 3D files. This will alter the design development methods, as 3D Printing facilitates the immediate visualization of the model yet requires heightened precision in the design. Furthermore, BIM software and free-form modelling software allow for design in a 3D environment, resulting in two-dimensional drawings, which reverses the centuries-old procedure. This process will soon enable continuity and better control over all project stages, from ideation to engineering to the 3D Printing of the physical model to the production of building components with file-to-factory processes. Such non-standardized production and construction automation methods will pave the way for a new kind of "digital craftsmanship", merging traditional technical skills with technological innovation and repairing the disconnect between thought and hand caused by the introduction of CAD software which quickly replaced manual skill in the creation of drawings. Here, 3D Printing can have a major role, as it can be used to create architectural and concept models to represent a project and customize pieces and components of the building.

**Barriers that need to be addressed in order for 3D Printing to become a viable option for housing construction**

Although the potential advantages of 3D Printing seem promising, the existing state of the technology has factors that prevent its growth in the construction industry. Figure 1 outlines the barriers to the use of 3D Printing in housing construction.



*Figure 1: Barriers to the use of 3D Printing in Housing Construction*

*Uncertainty regarding the size of demand for mass customization*

3D printing technology is maturing and used in prototyping and distributed manufacturing. It has already been used to manufacture small prototypes in industries such as medicine, manufacturing and the educational sector. 3D Printing in construction is still in its infancy, and there are challenges which are associated with its growth. According to the literature, ordinary 3D printers are only capable of producing an object smaller than the size of the printer casing, which is a restriction for the construction industry if there is a need to do mass production. Larger printers exist, but they need to be housed in an area that accommodates their size. (Attaran, 2017; Olsson et al., 2019; Labonnote et al., 2016).

For the construction industry, 3D printing technology prints small components of the building assembled on-site to produce the finished goods. When large quantities are required, the 3D printer is relatively slow compared to traditional mass production. This consumes additional time, which would deter from the advantages. However, it is used for mass customization because it can create highly customized products in limited inventory (Attaran, 2017).

*Availability of high-strength printing materials.*

The materials used for the construction process must undergo four extrusion-based processes: pump ability, printability, buildability and open time. Pumpability is the easiness of the material to move through the delivery process. Printability is the reliability of depositing the material through a deposition device. Buildability is the resistance of the deposited wet material to deform under loads, and open time is the period in which these properties remain within the required tolerance (Labonnote et al., 2016). One of the structural requirements for construction is that when concrete is used during construction, it must be load-bearing immediately upon placement. However, previous research found that most additive manufacturing technologies involving concrete do not use the framework to confine the concrete. Instead, they deposit it through a nozzle to form successive layers along a path. This is a barrier when looking at the structural integrity of the building (Labonnote et al., 2016).

The materials produced by the 3D printer should be relevant to construction (Strauss, 2013). For this reason, printability and buildability have been reported as the most critical properties. The materials should be formulated so that the materials can bond with one another and still have time to cure. This, in turn, ensures that the required strength of the concrete is achieved. Additionally, large-scale construction involves large volumes of material which require storage, and when using 3D Printing, this factor needs to be considered. Therefore, the materials used by additive manufacturing must be affordable and lightweight in order to facilitate storage (Labonnote et al., 2016).

Finding materials for a 3D-printed building remains the biggest challenge. For example, the materials used in the Canal House require material development. Henkel developed the materials, and they are still running some tests with a newly developed eco-concrete that may be used in later stages of the Canal House project to increase the compressive strength of printed pieces. 3D technology uses developed materials which allow the creation of building components layer by layer, and the desired mixture has maximum workability and flowability, which makes it easier to be placed in layers. This process aims to reach the required bonding strength present in the normal concrete cast on site. The possible material solution for 3D Printing of building components could be sulphur concrete, a composite material made of sulphur and aggregates. After the sulphur concrete has undergone the required heating and cooling, it reaches the target strength without prolonged curing time like normal concrete (Uppala and Tadikamalla, 2017).

*Knowledge and Awareness*

Campbell er al. (2011) expand on the novelty of the technology by reviewing the recent additive manufacturing developments within South Africa. There are not many 3D printing professionals in the country, and the adoption of 3D Printing has been limited to higher learning institutions for research purposes and a limited number of private companies (Campbell, De Beer and Pei, 2011). Wohlers (2009,) as cited by Campbell et al. (2011), gives credit to The Rapid Product Development Association of South Africa (RAPDASA) for the growth in awareness and adoption of 3D Printing, resulting in the growth of industrial usage outgrowing the growth of academic usage. De Beer (2008), as cited by Campbell et al. (2011), found that the use of 3D Printing technology grew by 50% between 2000 and 2008, while 3D printing machines in use increased proportionally by 80% in the same period.

However, Campbell et al. (2011) write that this significant progress is only witnessed in sectors including "government and military, aerospace, automotive, medical, academic and research, sports, gaming and ICT, toys, art and craft, consumer goods as well as other ad-hoc projects". Not included in the construction industry, so it is fair to say that this progress in awareness and growth in the adoption of 3D Printing does not include the construction industry.

*Government development programmes*

McCutcheon (2008) notes that the need to generate employment in the climate of low-skilled labour is the adoption of labour-intensive construction practices. McCutcheon (2008) describes 'labour-intensive' as an operation in which proportionately more labour is used than other factors of production. If the Government views it as important to address the issue of poverty and inequality and therefore has responded to this by deeming it a need for employment nationally and implementing government development programs across the country, then 3D Printing Technology would not be a suitable construction technology.

*Cost*

According to Attaran (2017), the cost is a barrier to using 3D printing technology because of the product's unavailability. The equipment required to 3D print is very costly, in the range of about $500,000, and the materials used in the printer can be expensive as an implication of the novelty of the product. There are not many producers of the materials in the construction industry yet (Attaran, 2017). Furthermore, there is reluctance in contracting companies to invest in 3D printing technology. The initial cost of purchasing a 3D printer is expensive. However, the long-term benefits of time and cost savings could be obtained in the future. Purchasing the printer would mean that contracting companies need to consider a new set of skilled labour and management that will operate the machine.

*The housing project*

The findings on the application of 3D printing technology in the construction industry in other countries have led to a fear of adopting the technology due to all the challenges early adopters face (Wu et al., 2016). Using the Winsun 3D printer showed the challenges faced when 3D Printing a building (Wu et al., 2016). These challenges include that it compromises the structural integrity of the building. Bos et al. (2016) question the use of additive manufacturing for the construction of load-bearing walls with sufficient "robustness and ductility" The Winsun 3D printer does not account for the installation of services such as electricity, plumbing and HVAC; the implication is that the walls need to be drilled for the pipes and sanitary ware and the structural integrity of the wall is compromised (Wu et al., 2016).

*Risk Allocation*

A risk is an uncertain event or condition that, if it occurs, has a positive or negative effect on a project's objectives. However, project risks are specific risks associated with a unique construction project with its specific requirements (Alarcón et al., 2011). Often, when a client directs their capital towards a construction project, that investment is usually the largest they make, whether individual clients or large corporations. The fact that this is a significant investment result in the clients being risk-averse because construction projects are always associated with high-risk profiles. Therefore, the clients are unwilling to accept the additional risk associated with innovation. As a result, clients seek the choice that provides a sense of security and confidence in their investment, provided via the use of tried and tested methods and materials in their construction projects (Rosenfield, 1994).

The desire to avoid innovation because of the uncertainty surrounding it is not only limited to the clients but also extends to the design team. The design team is wary of applying innovative ideas and solutions in the case that they could fail, therefore resulting in them suggesting that the construction project make use of methods and materials that have been proven to work so that they avoid criticism and the possibility of liability claims (Rosenfield, 1994).

Contractors in the industry are also wary of innovations because of the associated risks. Usually, there are various components on a construction project; therefore, multiple trades are contracted to multiple specialist subcontractors. The main contractor avoids the risk of innovation by clearly defining the legal requirements within those contracts, thereby passing down the risk down the supply chain (Blayse and Manley, 2004). Therefore, the very nature of the contractual risk allocation between the parties involved in a construction project discourages innovation, especially when there is a possibility that claims, disputes and litigation could arise from the slightest deviation from what is contractually agreed upon (Naoum et al., 2010). The result is that contractors and sub-contractors choose to avoid innovation in projects to utilize tried and tested methods to mitigate the risk.

*Fragmentation and Structure of Production of the construction industry*

Fragmentation is defined in terms of the number of subcontractors/specialists involved in construction projects and in terms of its effects on the multiple processes in construction projects. Therefore, concerning the construction industry, fragmentation is the division resulting from the increasing number of participants involved in all building project processes. Furthermore, this division has come about due to the growing demand for differentiation and specialization as building projects increase in size and complexity (Nawi et al., 2014). Fragmentation is not only limited to individual construction projects. However, it can also occur at an industry level in which the number of small and medium-sized enterprises increases and the number of large firms decreases (Alashwal et al., 2011).

Generally, the fragmented nature of the construction industry has the following impact on the industry because it leads to the elimination of the opportunity for learning and innovating (Alashwal et al., 2011); It decreases the intention to invest in innovation and blocks the mutual sharing of information and knowledge (Alashwal, 2011); the fragmented nature inhibits knowledge production which then leads to a low level of productivity (Egbu, 2006); the fragmented nature leads to numerous contractual agreements between the different participants involved in the project, and this leads to difficulties in the integration of information (Tijhuis and Fellows, 2012).

The nature of the construction industry results in industry relationships which have an extremely significant influence on construction innovation; however, projects in the industry are of a temporary or one-off nature, and the impact that this has is the discontinuity in the knowledge development and knowledge transfer of the participants in the industry. In the construction industry, the traditional construction processes are conducted sequentially and are characterized by a lack of interaction between contractors and designers during the design and construction phase, which results in inefficiencies during the construction phase, hinders the integration of teams on projects and does not encourage innovation in the production processes.

According to Miozzo and Dewick (2004), the products of the construction industry are of a nature that does not necessarily result in the conditions necessary for innovation. This is because built structures are expected to be durable, so tested and tried techniques are preferred to ensure this expectation. Additionally, products in the industry are expected to have a long life span. Therefore, suppliers and manufacturers tend to maintain stocks of materials and parts for future use, reducing the supplier's and manufacturer's incentives to innovate and change their product ranges (Blayse and Manley, 2004).

*Procurement systems*

Procurement is an integral aspect of a construction project. It includes the sourcing, purchasing and all activities related to providing knowledge, labour, construction equipment, materials, supplies, supervision, and management services required to complete the project. Furthermore, effective procurement tends to focus on securing a deliverable and affordable solution that best meets the client's needs and providing a firm contractual basis against which delivery and performance can be assessed.

Procurement systems in the construction industry place a premium on speed and urgency, as well as competition based on price alone. The establishment of rigid role responsibilities within a construction project, in addition to promoting hostile and self-preservation behaviour, are also aspects that are emphasized within the procurement systems used in the construction industry, and it is these procurement systems that discourage contractors from pursuing novel building solutions and are most delirious to innovation (Blayse et al., 2004).

Procurement systems available to construction clients include the traditional contract, design-build, lump-sum, construction management and build-own-operate-transfer systems. The traditional contract is the most conservative contract that hinders innovation to a great extent. This is so because the traditional procurement system is characterized by a lack of a sense of identity, promotion of a confrontational culture and a lack of feedback loops or coordination between the design and construction phases (Dainty et al., 2001). Furthermore, to encourage innovation in the construction industry, a more innovative procurement method should be implemented within construction projects, and innovative procurement methods utilize a well-integrated team. This aspect drives innovation (Walker et al., 2003).

Procurement methods that encourage construction team integration improve innovation outcomes. On complex projects involving multiple stakeholders and subcontractors, procurement systems such as design-build, construction management, and project management help address the industry's fragmented nature by incorporating the integration of the various participants and leading to good innovation outcomes. This is because the design and construction phases, and sometimes financing and operation, are integrated, which leads to improved design constructability and the financial aspects of the project through innovation (Blayse et al., 2004).

*Regulations*

The term regulation refers to the political and legal actions a government may consider necessary to oversee the activity in the construction industry and the behaviour of private sectors in the economy (Benmansour and Hogg., 2002). The effects of regulation depend on various factors, such as the motivation for regulation, the nature of the regulatory instruments and structure of the regulatory process, the industry's economic characteristics, and the legal and political environment in which regulation takes place (Joskow, 1989). Government regulatory policies and legislations generally exert a significant influence on demand and play an important role in directing the path and the rate of technological change, as well as encouraging or discouraging innovative activity (Gann and Salter, 2000). Furthermore, inappropriate regulation may also discourage research efforts by firms and distort the choice of technologies that are adopted. This may be due to the structure of the industry and its ability to adapt to challenges. (Benmansour et al., 2002).

Currently, there is little incentive or reward for exceeding or diverting from standards in the construction industry, encouraging the same tried and tested processes to be re-used to meet the client's requirements and hindering innovative advances. Regulatory policies and legislation are also imposed on construction projects on a local basis in places where a unitary national government does not regulate construction but may be devolved to smaller local government entities. This has the effect of local regulations protecting local cultures and practices. However, construction companies may fail to adapt to changes, hindering innovation and its potential benefits (Hardie, 2011). Additionally, most building codes and procurement standards make no provision or mention of 3D printing technology, making it difficult to legally implement 3D printing components onto large-scale projects (Kidwell, 2017; Malaeb et al., 2015; Uppala and Tadikamalla, 2017).

*The Size of the Printer*

The sheer size of the printer hinders it from producing a completely 3D-printed building because there will always be the need for traditionally built foundations and reinforcement. Currently, the largest printer is Winsun’s 20' tall, 40' wide, 120'long concrete printer, which can only produce buildings and not the entire building on site.

**The potential of 3D Printing Technology to revolutionize the way we build houses and the implications of this technology for the future of housing construction**

The accessibility of 3D printers for both industrial and general public use has grown dramatically in the past decade. This technology is quickly approaching mainstream adoption as a highly flexible processing technique that can be applied to plastic, metal, ceramic, concrete and other building materials. Global sales that include the devices, materials and services for industrial-scale to consumer-based printers have grown by an annual average of more than 33% over the last three years to $ 4.1 billion in 2014. The main reason for this growth is that the early patents related to 3D printing devices and processes have expired. This has resulted in many start-up companies developing new 3D printer devices that have pushed innovative design approaches while driving down the cost, in some cases well below $1000 for an entry-level printer (Stansbury and Idacavage, 2016).

As expansion of the 3D printing field continues, practical factors such as processing costs, which include material costs, production speed and volume and energy costs, are now being carefully evaluated alongside that involved with more traditional manufacturing processes (Stansbury and Idacavage, 2016). This rapid evolution of the market has placed 3D printers in tremendously varied industrial settings but also in K-12 schools, public libraries, university classrooms and laboratories and, more commonly now, in homes. Current growth leaders of this technology are within biomedical applications.

**Conclusion**

In conclusion, 3D Printing is a rapidly evolving technology that has the potential to revolutionize the way we build and construct housing. It has the potential to reduce costs, improve the speed of construction, and open up new possibilities for customization. Despite this, implementing 3D printing technology in the construction industry is still in its infancy. It is associated with several barriers to its use in the housing construction sector, such as the availability of high-strength printing materials, cost, knowledge and awareness of the technology, and associated risks. Governments and industries need to invest in research and development to overcome these barriers and ensure that 3D Printing can be used to construct housing safely and effectively. With the right investment and support, 3D Printing could revolutionize how we build housing and provide more affordable and sustainable housing solutions. There is also the need for persistent when trying out something new, as there aften barriers and difficulties along the way.

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