3D Printing Technology for Real Estate Report

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Overview of 3D Printing Technology

Overview: 3D Printing is a technology that can realize material cost reduction, labor efficiency, and environment sustainability.

3D printing technology is a manufacturing process of making three-dimensional solid objects based on a self-designed digital model. All 3D printing processes require software, hardware, and material to work together. The creation of a 3D printed object is achieved using additive processes, which is opposite with the traditional manufacturing process of cutting the material; thus, it can approach environmental sustainability by reducing manufacturing waste and by using recyclable material. The 3D manufacturing techniques are mainly referred to extrusion and casting, an efficient process to create complex and complete parts, such as product shells, prosthetics, wind turbines, and even a house. **The main benefits of applying 3D printing techniques are 1. Less labor-intensive 2. product design is freed 3. Product is more customizable 4. Less waste 5. Lower cost.** From simple handicrafts to automobile bone structure, an increasing number of industries manufacture the product with the aid of 3D printing techniques. It is expected that the 3D printing trend will gradually impact industries' business models and serve as an alternative eco-friendly selection. **Figure 1** and **Figure 2** shows the cost savings between 3D printing and conventional construction from International Construction Cost Survey.

Figure 1 Construction Labor Cost

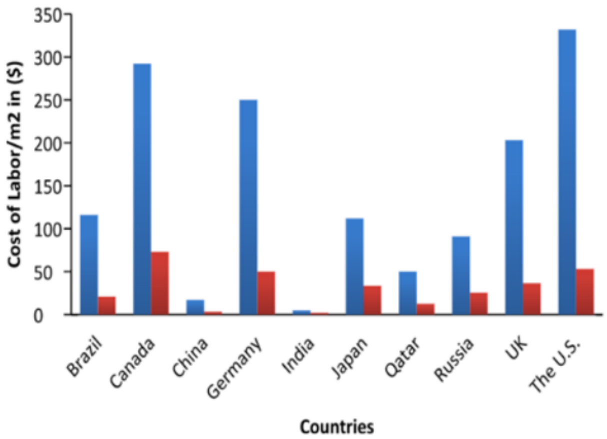
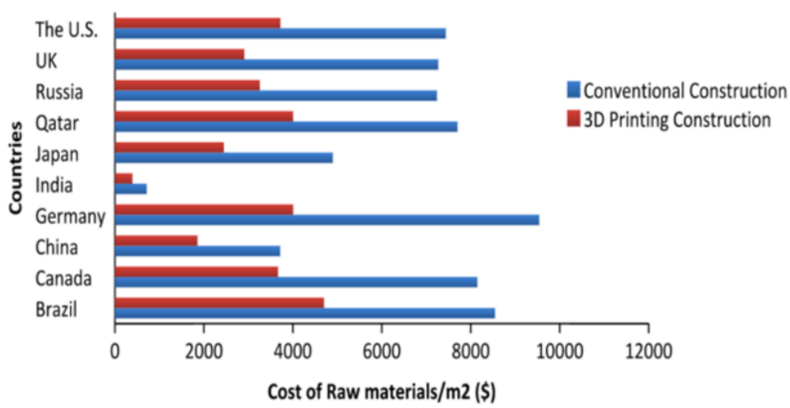


Figure 2 Construction Materials Cost



3D Printing in Construction History

Overview: 1984 SLA techniques, 2006 Contour Crafting System, 2014 first 3D house in Dutch, 2015 first 3D bridge in Dutch, 2015 first printed room…. What else?

In 1984, Charles "Chuck" Hull invented stereolithography (SLA), a method of 3D printing where designers create a 3D model that is then printed layer by layer into a solid, physical object. The SLA process involves pointing a UV laser at a liquid photopolymer which makes it stable. The 3D printers most used in the consumer sector are SLA printers, and one of the earliest models for 3D printing was to print tabletop scale models for architecture firms. These models helped in the design process and were valuable tools for planning building projects. By the 1990s, several organizations began experimenting with 3D printing to produce modular components of full-scale projects. However, the 3D printing technology was still far from printing a building. In 2006, Dr. Behrokh Khoshnevis created the Contour Crafting System, an enormous 3D printer designed to print buildings on site. It uses a crane to do the printing, and concrete as the medium, to lay down a building's structural elements. In 2014, a Dutch firm (DUS Architect) demonstrated the potential for 3D printed architecture by building 86 square feet house out of 3D printed plastic in Amsterdam. In 2015, the Dutch firm MX3D began printing a full-scale steel bridge to be installed in downtown Amsterdam, aiming to make steel construction more cost-efficient and faster. The queen officially opened the bridge for use in 2021. In 2015, Lewis Grand Hotel in the Philippines expanded the 3D printed room with the size of 1399 square feet. The project has saved 60% building costs, according to the project leader Andrey Rudenko.

2016 was the prospering year for 3D printing construction. More and more companies start taking models outside the R&D laboratory and put them into practical application. In January 2016, architecture firm SOM announced to produce highly efficient dwelling structures consisting of a 3D printed pod and a combination of renewable solar and natural gas energy systems. The goal of this project is to build the shelter in formerly inaccessible and remote locations, as well as a sustainable long-term shelter for disaster relief. In June 2016, Chinese company HuaShang Tenda constructed an entire concrete mansion in 45 days. The two-story, 4,305 square feet dwelling claims to be earthquake-proof. In late 2016, Chinese company Winsun built the first commercial building, "office of the future" in Dubai, with 2583 square feet. The structure is initially made in Shanghai and shipped to Dubai for on-site installation. In the same year, the officially recognized first 3D printed residential house was built in Moscow by Apis Cor. The house size is 409 square feet, using a mixture of solid elements and liquid polyurethane and decorating with wood flooring and is furnished with appliances from Samsung. In the year 2018, the first family moved into the 3D printed house in France- Yhnova House constructed by the University of Nantes, indicating the 3D printed house will enter the housing market shortly.

In the rest of 2018-2021, multiple types of houses are printed through 3D printing technology. With the aid of this technology, the construction industry can alter its process with safer, faster, and more flexible building techniques.

Market Analysis

Real-Estate Market and House Affordability

Overview: Both EU and US are experiencing historical high in house and rent prices, and both have potential real-estate bubble risk. Price-to-income ratios keeps rising, indicating increasing number of people are facing house affordability challenge.

- Eurozone

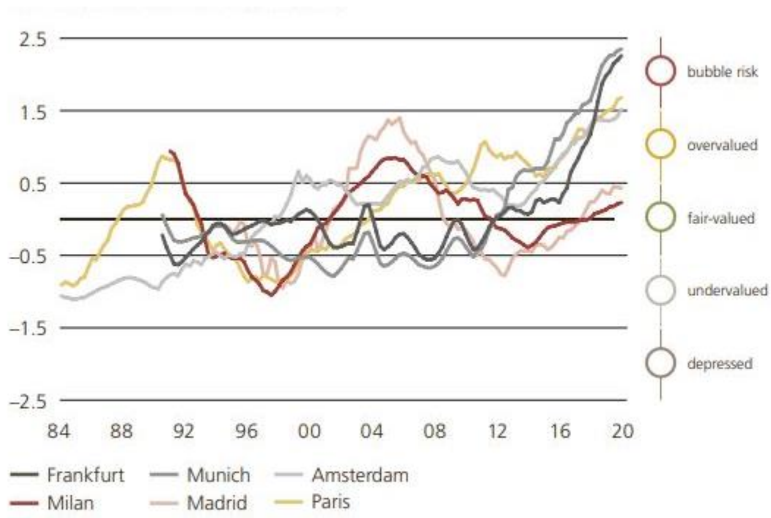
The houses shortage with increasing demand occurs globally. The overall construction is lower than in past decades, resulting in limited house supply and soaring house prices. **Figure 3** displays the trend in both house and rent prices in past decades in Eurozone.

Figure 3 Trends in House and Rent Prices (EU)

Source: Eurostats

Since 2018, more than 82 million EU citizens with low incomes have spent more than 40% of their disposable income on housing, compared to 9.4% of the general population in the EU [1]. Tenants are more affected by increasing house prices, almost four times as likely than homeowners to suffer from housing cost overburden. The bubble risk index made by UBS in **Figure 4** indicates **that main cities in Eurozone are experiencing real-estate bubble risk (> 1.5)**

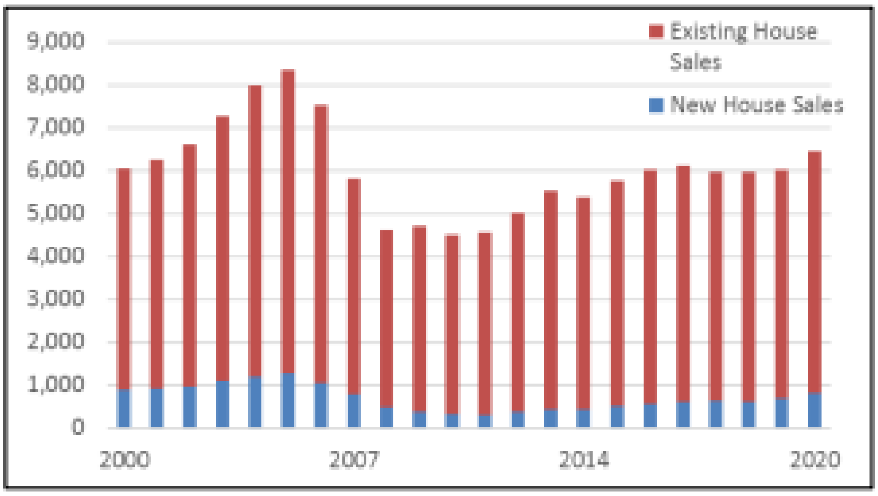
Figure 4 UBS Global Real-Estate Bubble Risk Index-EU



- United States

Figure 5 shows in 2020, both sales of existing and new houses are increased by 5.6% and 19.3%. The momentary uptrend sales can primarily be attributed to the interest rate on a 30-year fixed-rate mortgage continued declining to the record low of 2.8% at the end of 2020. However, although the number of sales homes increase, **the total supply of homes for sale hit historic lows in 2020.**

Figure 5 Annual House Sales in thousands



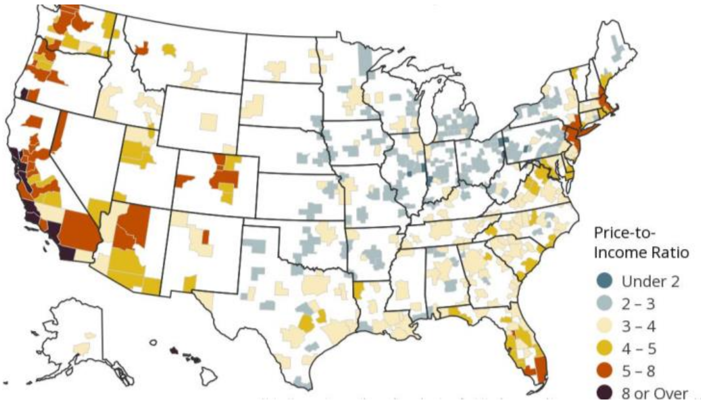
Source: Department of Housing and Urban Development

Figure 6 Home for Sale Hit Historical Low

Source: The State of the Nation's Housing, Harvard University

The pandemic made the shortage even worse, preventing many potential sellers from putting their homes on the market, resulting in upward pressure on home prices because of low inventories. **Figure 6** shows the home **price-to-income ratios keep soaring and up to 4** in the first quarter of 2021. A family must invest four times their annual family income for the purchase of their home. The bubble index risk score shows a relatively unstable and overvalued status (0.5~1.5), stating that **the problem of high housing price and affordability in main cities**, especially in the west coast areas.

Figure 7 Home to Income Ratio - US



Source: Joint Center for Housing Studies, Harvard University

Figure 8 UBS Global Real-Estate Bubble Risk Index-US

- House Affordability

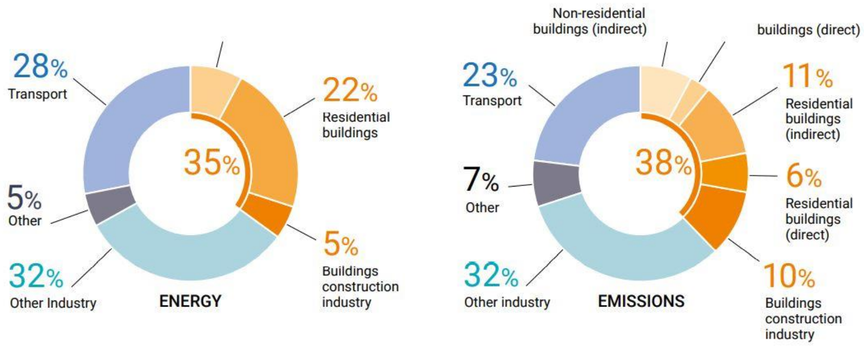
Social housing showed an uptrend in the globe as the housing price keeps displaying an upward trend**. In all EU countries, studies show that at least 700,000 people are living in emergency accommodation**, 70% more than decades ago. **According to a 2020 US national survey, there are 580,466 people experiencing homelessness on a given night**, 38.9% are unsheltered [2]. The increasing price of housing has brought a negative impact for the place with a high population.

3D-Printed houses' Potential in Green Buildings Market

Overview: Traditional construction method generates historical high level of Co2 last year, and 3D printed house may be the solution for sustainability. The 3D construction market growth will reach $4.63 million in 2021 at a compound growth rate of 21.7%.

In the globe, there are 104 of 194 countries signed the Paris Agreement to improve building energy efficiency and to meet mitigation targets but only 68 of them have abided by the rules and obtained building energy codes **[3]. Carbon emission reached the highest level** through building construction and emission ever although the global construction speed slowed to 2.6% since 2019 [4]. Nowadays, **buildings are responsible for 6% for all global emissions, 38% of global carbon emissions, and 35% of global energy use.**

Figure 9 Global Share of buildings and construction final energy and emissions



Source: THE 2020 GLOBAL STATUS REPORT FOR BUILDINGS AND CONSTRUCTION

Under governments regulating and enforcing society's sustainability and social responsibility objectives in recent years, more and more firms start using alternative materials for the new building project. According to the survey, **over 47% of the surveyed businesses planned to build about 60% of their construction projects using green technology** [5].

3D printing technology is one of the innovative solutions to optimize sustainable materials for building. 3D printed home can reduce 70% of carbon footprint with record speed. In recent years, the increasing use of **3D printing in the construction industry is driving market growth and is expected to reach $4.63 million in 2021 at a compound growth rate of 21.7%. The market is expected to reach $329.01 million in 2025 at a growth rate of 190%** [6]. The capability to build complex structures under a reasonable price range stimulates the demand for 3D printing construction in the new building project worldwide. Moreover, 3D printing reduces labor costs by 50%-80%, production time by 50%-70%, and construction waste by 30%-60% compared to traditional processes.

3D printing technology is being widely used for more and more complex structures in construction, demonstrating its valuable advantages, including high accuracy, improved efficiency, lowered labor cost, and greater speed. Lower cost of construction may turn out to be a lower price of the house, and finally, improve the housing affordability while avoiding the waste of building space. The printed house is a new favorite in the housing market nowadays and may be the potential solution to the challenges of the real-estate industry in the future.

Environmental Analysis

Overview: 3D printed house has cleaner construction process, less energy consumption. The Co2 emissions from 3D printed house is 6.3 times less; and energy consumption is 4 times less than from conventional building.

Through the Life Cycle Analysis (LCA), we can evaluate whether 3D printed house is much more sustainable and has smaller impact on environment than the traditional construction process. By analyzing the environmental effects associated with the initial gathering of raw materials from the earth until the point at which all residuals are returned to the earth", or the so-called "cradle-to-grave process", we can evaluate the product's life cycle consumption and transform to carbon emission level. The data information is mainly from research papers [7] and [8], and all values are counted average from terrace house type, 60m^2 (functional unit), for the efficient comparison between 3D printed house and traditional house.

Table 1 Materials and process in 3D printed buildings

Materials	SimaPro Reference	unit	Building (kg)	Foundation (kg)	Roof (kg)
Cement+flyash	Portland cement, strength class Z 42.5, at plant/CH S	kg	25699.8	11160	9674.05
Silica fume	Silica sand, at plant/DE S	kg	2867.05	1245	1079.23
Sand	Sand, at mine/CH S	kg	42867.6	18615	16136.5
Water	Tap water, at user/CH S	kg	8014	3480	3016.6
Fibers	Glass fiber, at plant/RER S	kg	48	21	18
Transport	Lorry transport, Euro 0-4 mix, max payload RER S	kg	8394.93		
Transport of printer	Transport, lorry 16-32t, EURO5/RER S	tkm	500		
Transport of materials	Transport, lorry 16-32t, EURO5/RER S	tkm	50		
Ceramic floor tiles	Ceramic tiles, at regional storage/CH S	kg	170.2		
Timber floor boards	Glued laminated timber, outdoor use, at plant/RER S	m3	331		
U-PVC frame	Window frame, aluminum, U+1.6 W/m2K, at plant/RER S	m2	192		
Hardwood timber	Door, inner, wood, at plant/RER S	m2	331		
Electricity (1440kWh)	Electricity, medium voltage, at grid/CH S	kWh	795.28	345.35	300

Table2 Materials and process in conventional buildings

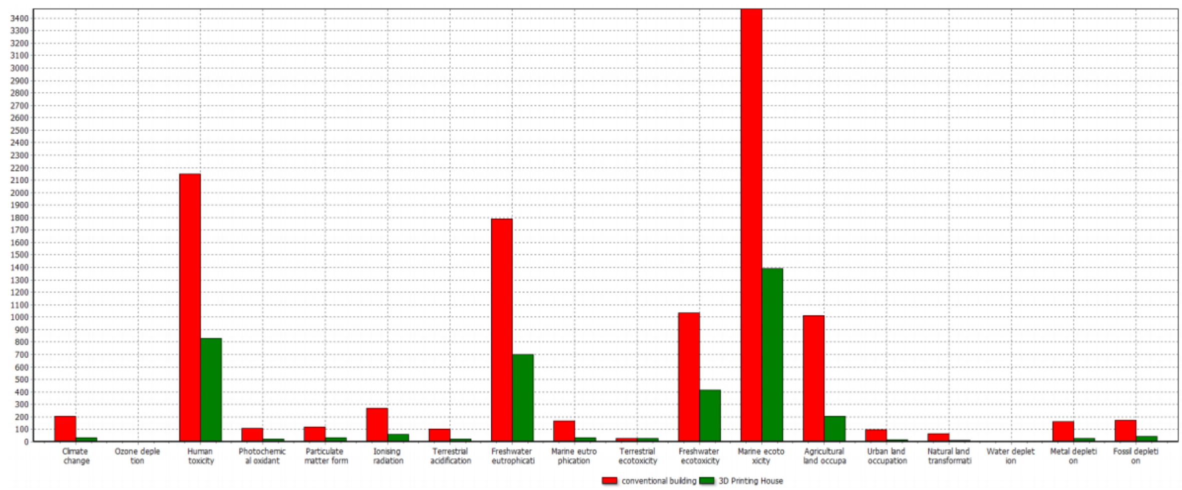
Materials	SimaPro Reference	unit	Building (kg)	Foundation (kg)	Roof (kg)
Brick (Imperial 9'')	Light clay brick, at plant/DE S	kg	30002	10956	
Cement mortar	Cement mortar, at plant/CH S	kg	7983	726	1079.23
Concrete block (aerated)	Aerated concrete block, type P4 05 reinforced	kg	6716	12906.85	
Concrete slab	Concrete, sole plate and foundation, at plant/CH S	kg	7097.14		
Sand and gravel	_16 sand, gravel and stone from quarry	kg	3312		
Concrete tiles	Ceramic tiles, at regional storage/CH S	kg			1991
Plaster board	Gypsum plaster board, at plant/CH S	kg	3088		
Softwood timber	Sawn timber, softwood, planed, air dried, at plant/RER S	m3	1362		
Timber floor boards	Glued laminated timber, outdoor use, at plant/RER S	m3	331		
U-PVC frame	Window frame, aluminum, U+1.6 W/m2K, at plant/RER S	m2	192		
Laminated floor	Three layered laminated board, at plant/RER S	m3	331		
Transport of materials	Transport of materials	tkm	3611.82	1487.61	67.91
Energy consumption	Electricity, medium voltage, at grid/CH S	kWh	3102.39	1285.06	61.26

Table 1 and **Table 2** show the estimated materials used to build the exact size of the house. From the table, it is obvious to find that **conventional buildings require more energy consumption during the whole operation, almost 4 times more than 3D printed houses**. The weight of transportation for the materials exists a huge gap between two constructions as well, with 50tkm in 3D printed house and 3611.82tkm for a conventional house. It is also the feasibility in transporting sufficient materials for building a house that 3D printed construction companies can launch their building projects in remote or undeveloped areas. For other materials in a different category, it is necessary to transform them into greenhouse gases' weight to analyze the impact to environment further. The multiplier for each type is built in SimaPro software database.

Table 3 Characterization results of the two alternatives

Impact Category	unit	3D printed building	Conventional building
Climate change	kg CO_2 eq	2.21E5	1.41E6
Ozone depletion	kg CFC-11 eq	0.017	0.0729
Human toxicity	kg 1,4-DB eq	9.95E4	2.57E5
Photochemical oxidant formation	kg NMVOC	980	5.37E3
Particulate matter formation	kg PM 10 eq	422	1.63E3
Ionizing radiation	kg U235 eq	7.41E4	3.39E5
Terrestrial acidification	kg SO2 eq	914	3.84E3
Freshwater eutrophication	kg P eq	88.5	225
Marine eutrophication	kg N eq	275	1.51E3
Terrestrial ecotoxicity	kg 1,4-DB eq	172	172
Freshwater ecotoxicity	kg 1,4-DB eq	1.77E3	4.41E3
Marine ecotoxicity	kg 1,4-DB eq	1.84E3	4.6E3
Agricultural land occupation	m2a	1.09E6	5.45E6
Urban land occupation	m2a	1.36E4	7.34E4
Natural land transformation	m2	144	759
Water depletion	m3	1.41E3	2.67E4
Metal depletion	kg Fe eq	1.19E4	7.23E4
Fossil depletion	kg oil eq	6.16E4	2.33E5

Figure 10 Normalization results of the two alternatives



After normalizing two constructions type, it is obvious that the **traditional construction type has a more negative impact on the environment.** The top 5 categories in **Figure 10** are Marine Ecotoxicity, Freshwater eutrophication, Human Toxicity, Freshwater Ecotoxicity, and Agricultural Land Occupation. These five effects stand most of the environmental destruction in all impact categories, and three of them are the water-related issue. The polluting waste and gases generated by construction and blasting when the houses are under demolition activities will harm the environment and heat up the temperature. The residue water from construction waste is discharged into the ocean and threatens marine creatures seriously. On the other hand, most materials in 3D printed houses are recyclable and can be used after demolition. Because those construction materials aren't processed to the waste products, both the marine and land environment are exposed to less toxic objects and greenhouse gases when comparing to the waste of traditional construction. **In a nutshell, the 3D printed house is more eco-friendly with less energy use, fewer greenhouse gas emissions, and less impact on the whole ecosystem.**

Product Analysis

Overview: Although the advantages of 3D printed house from customer's viewpoints are apparent- cheaper, freed to design, stronger vertical resistance, and eco-friendly, the house is facing the disadvantages- limited size, poor horizontal resistance, and lack of regulation protection.

Table 4 Residential house for sale

Project Name	Landscape	Size	Company/ Country	Price/sqft	Median price/sqft in the same area
Yhnova		1022 sqft	University of Nantes/ France	£166	£240
Palari Villas		1450 sqft	Palari Group/ USA	$410	$483

S-squared		1,400 sqft	SQ4D/ USA	$214	$280

Table 4 listed the three of the famous 3D-printed residential houses for sale. **The price /sqft is all less than the median price of other houses in the same area, cheaper 20%~30% on average.** As a real-estate product, 3D printed house has a competitive advantage in sales price per square feet and may appeal to potential customers who are experiencing the budget tight on purchasing a house. However, the price is not the only determinant to purchase a real-estate property. **The safety concern, resistance, location, sustainability score, design are also the factors that impact house selection**. The advantages and limitations of a 3D printed house from the perspective of customers are listed below. The analysis considers the final product from customer preference over the normal house and 3D printed house and excludes the pros and cons during the manufacturing process.

Product Advantages:

- Relatively Low Cost

Besides cheaper materials and reduced construction costs, less labor demand reduces the cost of safety measures and lowers the final price to a great extent. However, the types of houses printed so far are mainly bungalows, thus it is not sufficient to conclude that the 3D printed houses are always cheaper than a traditional house, given that different structures of the house may increase construction difficulty and the cost.

- Infinite Design Possibilities

The whole printing process is controlled by computer programs that can produce objects within an error of 5~10mm. The high accuracy and flexible modeling options contribute to design freedom, allowing architects to design creative and appealing house. The architects can also discuss with clients and create the external appearance based on clients demands, which is an important business strategy to personalized economy nowadays.

- Stronger vertical resistance

Due to its construction method, such as one-piece-formed structure and the threaded surface combined with the raw materials of sand and concrete, 3D reinforced wall is stronger than traditional concrete but lighter in weight; thus, 3D house has stronger vertical earthquakes resistance.

- Stronger thermal Insulation

The steel cage structure can be fully filled with thermal insulation materials to achieve a good thermal insulation effect. Also, the one- piece-formed house.

- Sustainability

The 3D printed house greatly reduces building dust pollution, smog, and material waste from materials to the construction process, compared to the traditional construction process. From the sustainability view, it can better achieve green environmental protection. If more and more countries legislate renewable energy incentives or green tax credits for real estate, the demand for cleaner construction methods will increase, and 3D printed houses may stand a larger share in the housing market.

Product Disadvantages:

- Unpredictable horizontal durability

Although alternate mixed concrete improves the vertical structure of the whole building, its lightweight indicates the poor durability for the horizontal impairment such as wind blow, accident car crash, or even gun shots or other crime events.

- Size limitation

One of the biggest limitations of 3D printed houses is scalability. Fully 3D printed houses cannot be taller than a certain height due to the lack of metal reinforcements. By far, most of the printed house is designed as single-story home due to the immature printing house techniques and lack of supportive materials that allows construction for tall building. As a result, the tall 3D printed office building will not appear in the expected short term.

- Compete with traditional real-estate market

Another obvious disadvantage of 3D printed houses is that the market is just getting started, although the application of 3D printing has existed for 20 years. Not only the construction method is lack of standard operating procedure, but also the establishment of related regulation is a long-term process. The traditional real-estate markets have developed complete and mature regulations to protect customers' rights, supported by the diverse insurance contract that allows clients to make long-term housing plans. When competing with traditional house markets, 3D printed houses may not be the first choice considering legal protection aspects.

Summary and Future Outlook

Overview: 3D printed house is the future trend and will be the solution for real-estate market in no doubt, but it needs to be supported by government and related regulation. From customer viewpoints, 3D printed house must find the method to solve the problem of limited space and horizontal resistance.

The field of 3D printing technology is rapidly innovating the housing market. With the enhanced environmental protection consciousness in modern society, the demand for a cleaner house manufacturing process increases. From the sustainability viewpoint, 3D printed houses generate less construction waste and protect the environment by using recyclable materials. Moreover, **the recent developments of 3D printed houses have shown its economically advantageous and potential future developments**. For instance, the cheaper, smaller 3D printed house can solve house affordability and supply shortage. 3D printing technique also has less restriction and fewer materials transportation costs; thus, it may be ideal for remote and undeveloped areas. If Government cooperate with 3D printing companies, legislating incentives and funding for the company's research, it will be feasible to make the urban redevelopment plan and **alleviate potential real-estate bubble risk by building 3D printed houses**. Although the 3D printing in house industry has boundless prospects in the future, the limitations by far are apparent, such as lack of horizontal resistance compared to traditional concrete houses and size restriction due to immature structure techniques in 3D printing and materials characteristics. From the home buyers' perspectives, these two determinants are essential when considering the safety and accommodate space. It is also because of its floor limitation that a house with large size can only be built in a remote place, but vertical expansion is still the solution in urban development. Several developments and research in the 3D printing house industry are still undergoing to solve the limitation on 3D printing techniques, and **it will lead to the revolution of house construction methods and infrastructural changes in the future with no doubt.**

Reference

[1] European Commission, *Urban property: prices, ownership and occupancy*

[2] The Council of Economic Advisers, *The State of Homelessness in America*

[3] World Green Building Council, *Annual Report 2020-2022*

[4] Global Alliance for Buildings and Construction, *2020 GLOBAL STATUS REPORT FOR BUILDINGS AND CONSTRUCTION*

[5] Dodge Data Analytics, *World Green Building Trends*

[6] The Business Research Company, *3D Printing Building Construction Global Market Report 2021*

[7] Elias Ali, *Life Cycle Assessment of 3D Printing Houses*

[8] Andrianaki, A., et al, *Life cycle assessmnet of 3D printed bulding modules*

[9] Jake Kidwell, *Best Practices and Applications of 3D Printing in the Construction Industry*

[10] UBS, *UBS Global Real Estate Bubble Index 2020*

[11] Housing Europe, *The State of Housing in Europe 2020*

[12] Congressional Research Service, *Introduction to U.S. Economy: Housing Market*

[13] Harvard University, *The State of the Nation's Housing 2020*

[14] CBRE RESEARCH, *Real Estate Market Outlook* 2020

[15] Steven, J., et al*, A systematic review and analysis of the viability of 3D-printed construction in remote environments*

[16] Truong, A.*, State-of-the-Art Review on 3D Printing Technology Applications in Construction*

[17] Mehmet, S., et al, *3D Printing of Buildings: Construction of the Sustainable Houses of the Future by BIM*