TECHNOLOGY SCAN: 3D PRINTING IN BUILDING AND CONSTRUCTION

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METHODOLOGY

1. Dataset used for the report

The patent dataset was retrieved on 22 February 2019 and comprises worldwide patent applications relating to 3D printing in building and construction published in 2009-2018.

Relevant business information, market data, and national policies that are available from commercial databases or on the web are also used to support the findings of the report.

2. Counting the number of inventions

This report counts the number of inventions by the total number of unique patent families and utility models. Counting individual patent applications will result in double counting as each patent family may contain several patent publications if the applicant files the same invention for patent protection in multiple destinations. As a patent family is a group of patent applications relating to the same invention, analyses based on counting one invention per unique patent family can reflect innovation activity more accurately.

3. Formulation of search strings

To ensure optimal recall and accuracy of the data sets retrieved, the search strings used in this study were formulated by incorporating keywords (and their variants), as well as relevant patent classification codes and indexes, e.g. International Patent Classification (IPC) and Cooperative Patent Classification (CPC).

4. Grouping of technology domains

Grouping of individual patent documents into the respective technology domains was carried out based on patent classifications codes, text-mining and semantic analysis of the patent specifications in particular claims, titles, abstracts, as well as a manual review of the individual patent applications.

5. Growth rate calculation

Annual growth rate refers to the average annual growth and was derived by using the best-fit exponential line method for the set of data, $y = a*e^{bx}$, where b is the growth rate.

CONTENTS

INTRODUCTION

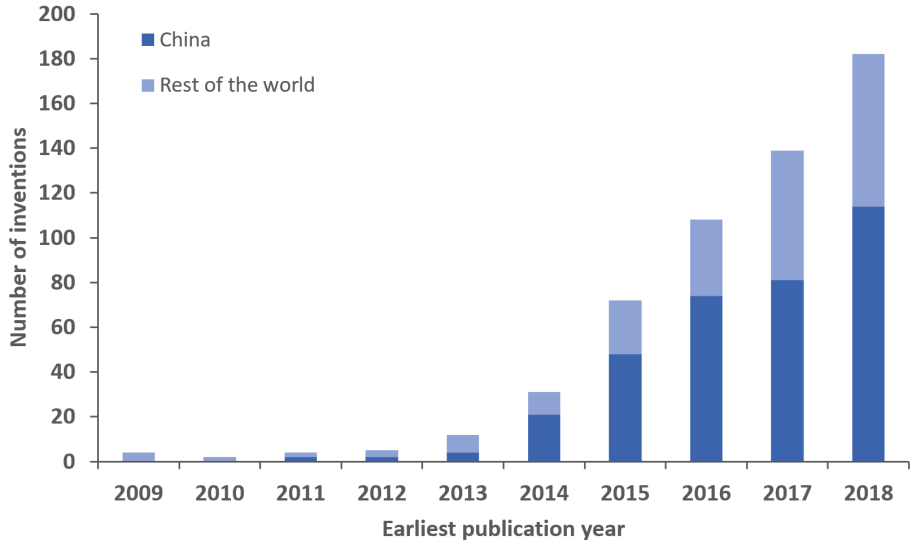
One single operator overseeing the construction of a large building. Reduced construction costs coupled with structures built in accelerated time. More complex architectural design. These are increasingly acknowledged as advantages of deploying 3D printing in the labour-intensive building and construction industry, as well as solutions to the problems entrenched in the industry, including safety issues, long construction time, massive waste and carbon generation, etc.

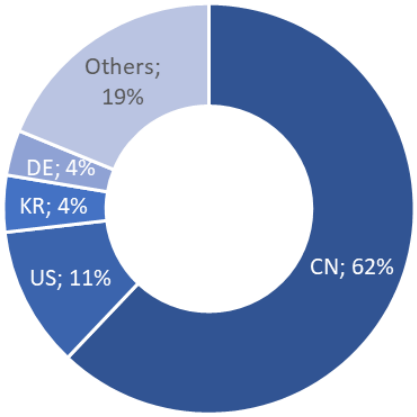
While the deployment of 3D printing in the building and construction industry is still in its infancy, its application is steadily gaining traction, given its potential to revolutionise the industry. Having already witnessed deployable prototypes being 3D-printed since 2014[1,2,3], we should expect to see more 3D printed-infrastructure in the next decade.[4]

This study provides an overview of this nascent field, while highlighting some of the lead players and interesting innovative technologies observed from patent data. Aside from providing a high level understanding of up-and-coming technologies in the building and construction industry, this report will also offer insights on potential areas for continued innovation and technology adoption.

OVERVIEW OF INNOVATION INTENSITY

A nascent field gaining traction





Based on globally published patent data, there were a total of only 559 published inventions during the surveyed period of 2009-2018. Despite the small numbers, the interest in this area has been rising, growing at an annual rate of 42% in the period between 2014-2018. China applicants are the major innovation contributors — 62% of all published inventions originated from China during this period.

As reflected by the low number of published inventions, 3D printing in building and construction remained relatively unexplored from 2009 to 2013, even amongst the top countries. This was, however, followed by a sharp increase in the number of patent filings in 2014, mainly attributed to applications in China.

The emphasis on innovation amongst China applicants stems from the Chinese government's push for 3D printing technology. Pioneered in several phases since 2015, starting from the "made in China 2025" initiative, the Chinese government views 3D printing as a critical enabler of industry advancement, thereby placing huge emphasis on the development of the 3D printing/ additive manufacturing industry with the aim of making China a world leader in 3D printing.[5] China's rapid urbanisation and rising population has also stimulated a large number of construction projects, and companies there are clearly looking to exploit the potential benefits of deploying 3D printing in building and construction.[6] And with the first mover advantage, China is expected to continue to lead innovative developments in this industry into the next decade.

OVERVIEW OF INNOVATION INTENSITY

China is the leading market for patent protection

Market of protection*	Country of origin**																		Total filing
	AT	AU	CH	CN	DE	DK	ES	FI	FR	UK	IL	IT	JP	KR	MT	NL	RU	UA	US	
CN		3		380	3		1		3	2	1	2		2		2	1		5	405
US		5	2	4	4	1	1	1	3	2	1	3				2	2	2	70	103
EP	4	5	2	1	7	1	1	1	4	3		2			6	3			10	50
KR		2												37					1	40
CA		5	1		1	1			1		1	1				1	1		8	21
DE					20														1	21
JP		4								2	1		7						4	18
FR									17											17
AU		5			1	1				1		1				1			4	14
RU									1								11		1	13

**Market of protection of an invention is defined by all the jurisdictions in which the particular invention is filed in*

***The numbers in the heatmap denote the number of published patent applications filed by innovators from the respective country of origin, in the specific market*

CN – China, US – United States of America, EP – Europe, KR – Korea, CA – Canada, DE – Germany, JP – Japan, FR – France, AU – Australia, RU – Russia, AT – Austria, CH – Switzerland, DK – Denmark, ES – Spain, FI – Finland, FR – France, GB – Great Britain, IL – Israel, IT – Italy, MT – Malta, NL – Netherlands. UA – Ukraine

Given this is a nascent field led by China innovators, it is not surprising that China is the market with the most number of patent filings (405), followed by the U.S. (103) and Europe (50) as the second and third largest markets, respectively. A deeper analysis revealed that 93.8% of Chinese patent applications were filed by its native applicants. In contrast, the U.S. market appeared to be more attractive globally, with 32% of its patent filings made by foreign applicants.

OVERVIEW OF INNOVATION INTENSITY

Focus by China entities on building infrastructure through 3D printing

China applicants are currently dominating inventions relating to the usage of 3D printing for building and construction, with nine of the top ten patent filers in this area worldwide, coming from China.

Applicant	No. of inventions	Innovation focus
Shanghai Construction Group	43	Printing of high-rise building using automated climbing and telescopic mechanisms
Ying Chuang Construction Technology (WinSun)	34	Scaffold and supporting structures for building printers, and printed products such as wall, floor, column, etc.
China Construction Eighth Engineering Div	26	Workflow to combine 3D printing into traditional pre-casting of wall, floor, beam, etc.
Shanghai Yannuo Building Materials	13	Printed wall with improved properties (mechanical reinforced, sound barrier)
Caterpillar Inc.	10	Control system for printer coordinates in a construction field & positioning of the mechanical parts for printing
China Minsheng Drawin Technology Investment	8	Printed piping system for bathroom
Dou Shupeng	7*	Printhead
Kejia Construction	6*	Workflow to combine 3D printing into traditional building construction for wall, floor, ceiling, etc.
China MCC17	6	BIM, printhead, printed structures
Tongji University	5	Printer for buildings and tunnel printing

**Portfolio includes a high proportion of utility models*

Top filer Shanghai Construction Group has been focusing on the development of 3D printers for the printing of high-rise buildings, foundations, bridges, underground tunnels, railways and other infrastructures. Particularly, the company has recently patented a specialised printer designed with telescoping, climbing, and lifting mechanisms, that enables the automated and continuous printing of high-rise buildings.[7] In addition, many of its recent patent applications have received positive examination results from China's National Intellectual Property Administration. These inventions would give Shanghai Construction Group a strong competitive advantage when it comes to commercial exploitation in the coming years.

Ying Chuang Construction Technology, more commonly known as WinSun, has claimed many headlines in recent years for its various 3D printed architectures, especially for its achievement of 3D-printing 10 houses in one day.[8] WinSun's technique involves extruding layers of concrete on top of one another, and it has produced various 3D printed structures including villas, traditional Chinese courtyards, public toilets, bus stops and more.[9] The company has leased its concrete 3D printers to Saudi Arabia in 2017 in a 1.5 billion dollar deal,[10] and has signed a memorandum of understanding with American Engineering Company (AECOM) in that same year, in an effort to achieve faster turnaround times with a lower carbon footprint for the whole construction process.[11]

OVERVIEW OF INNOVATION INTENSITY

Focus by China entities on building infrastructure through 3D printing (cont.)

China Construction Eighth Engineering Division, a subordinate to China state-owned enterprise, China State Construction Engineering Corporation, is a traditional pre-cast concrete manufacturer that has recently incorporated 3D printing technology into its pre-casting processes for building and constructions. Among the applications filed, 56% were granted mainly in the combination of 3D printing and pre-casting workflow, to produce building structures with unique properties such as thermal insulation, earthquake resistance, and improved shear stress distribution.

Rest of the world

Europe

Kapsch Trafficcom, Austria	4
Sika Technology, Switzerland	3
XtreeE, France	3

China

Shanghai Construction Group	43
Ying Chuang Construction Technology	34
China Construction Eighth Engineering Div	26

US

Caterpillar Inc.	9
University of Southern California	3
3M	2

Korea

Yonsei University Industry Academic	3
Chung Ang University Industry Academic	2
Whoborn Inc	1

Top native applicants in the US, Europe and Korea, on the other hand, have relatively smaller patent portfolio sizes. The most notable non-China leading applicant is well-known heavy machinery manufacturer, Caterpillar Inc, with a portfolio of 9 inventions. Entering this space only in 2016, Caterpillar has leveraged on its established expertise in construction machinery

OVERVIEW OF INNOVATION INTENSITY

Rest of the world (cont.)

design, and successfully integrated 3D printing capability into its existing product line. Its main research focus has been on the synergistic combination of 3D printers and construction equipment. Notably, most of its innovation activities relate to worksite construction operations, specifically to control the coordinates of its modular 3D printers based on real-time mapping of a terrain at the worksite.

In Singapore, there is currently limited interest in protecting 3D printing for building- and construction-related technologies, with a total of 6 patent applications. All applications were filed by foreign entities, with the top Singapore filer being Laing O'Rourke, which is famous for its FreeFAB™ technology involving 3D printing of curved formwork.

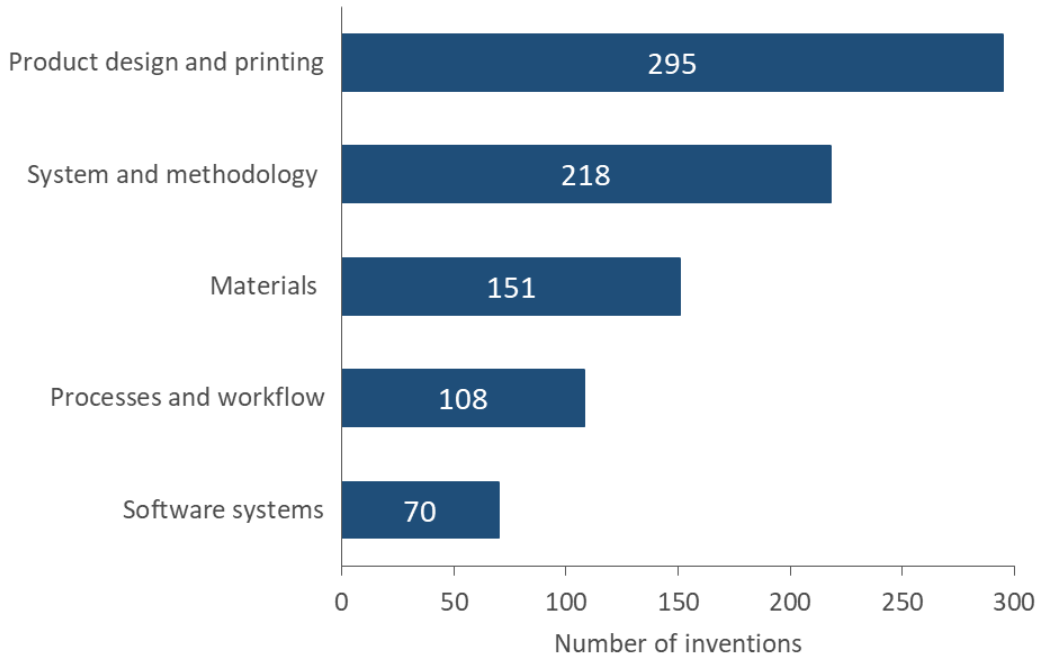
Earliest publication number	Earliest publication year	Applicant	Title
CA2909909A1	2014	Laing O'Rourke (AU)	Method for casting a construction element
CA2928481A1	2015	Laing O'Rourke (AU)	Method for fabricating an object
CA2976118A1	2015	Laing O'Rourke (AU)	Method for fabricating a composite construction element
CA2993095A1	2016	Laing O'Rourke (AU)	Method for fabricating a composite construction element
HK1204842A1	2015	Beyon 3D (Israel)	Method and system for fabrication of custom-made moulds and concrete-architectural components
WO 2016/079099 A1	2016	BPB United Kingdom (UK), Saint Gobain (FR)	Calcium sulphase-based products

BREAKDOWN OF CURRENT INNOVATION INTEREST

Rising interest in all aspects of 3D printing technology

The technology for 3D printing in the building and construction field can be categorised into 5 aspects:

- *Product design and printing*: Printing of infrastructure including buildings, modular components such as walls, ceilings, floors, beams, and complex architectural structures
- *System and methodology*: Mechanical design including peripheral components (scaffolds, cranes, supporting structures) of 3D printers for buildings, tunnels, bridges and other infrastructures
- *Processes and workflow*: 3D printing processes (e.g. fused deposition modelling, material jetting) and construction workflow
- *Materials*: 3D printing of materials (cement, concrete, polymers, steel, reinforcing fibres, etc.)
- *Software systems*: BIM, control system for machine coordinates & positioning, control system for process and workflow, scanning and modelling, mathematical model for structural and material optimisation



BREAKDOWN OF CURRENT INNOVATION INTEREST

Rising interest in all aspects of 3D printing technology (cont.)

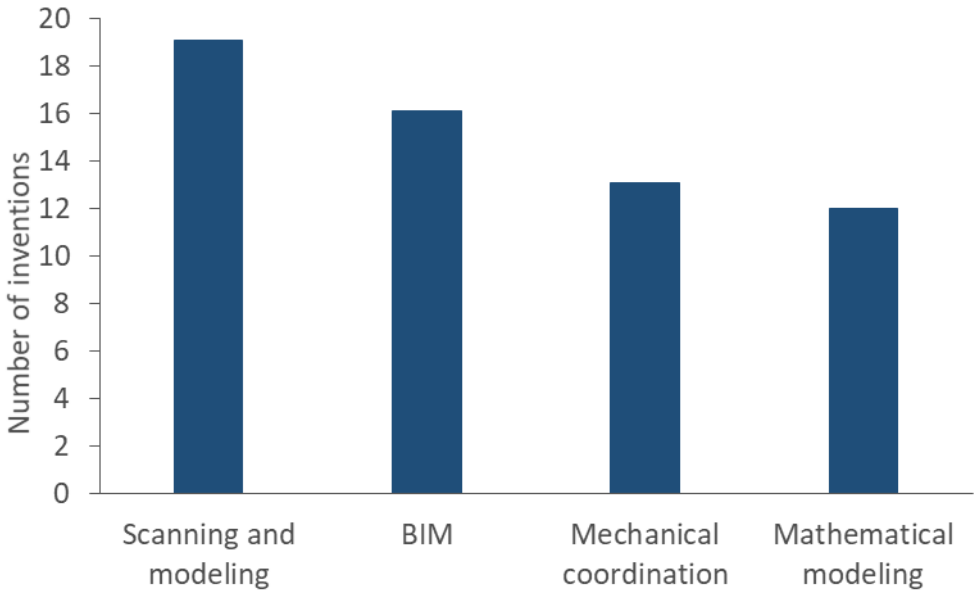
All technical aspects have displayed a clear double digit upward trend, with annual growths of 25%-48% in the recent 5 years. Representing 35% of overall published inventions, *product design and printing* has the highest innovation output, which is not unexpected. Printed products include walls, ceilings, beams, building components (such as mechanical parts for windows/ doors), and printed moulds for pre-fab — these are considered innovations with a low barrier to entry. In fact, more than one third of the 295 inventions in this domain were utility models that require a much lower standard of innovation than patents. Nevertheless, innovation activities were also observed in products with specialised functions (e.g. thermal insulation, sound barrier, waterproof, impact energy absorber, radio frequency shields, stress distribution, etc).

The *system and methodology* domain displayed the highest growth rate over the last 5 years (48.1% growth p.a. in 2014-2018). Most of the inventions in this domain were centred on the design challenges of large-format 3D printers and its peripheral mechanical structures such as scaffolds, cranes, platforms, material supply systems and robotic arms. Recently, this domain has seen signs of extreme printer re-designing, from a traditionally large-scale static printer towards a modular printing unit.

From the *materials* perspective, the industry seems to focus mainly on printing concrete. Among the 151 inventions relating to the domain of *materials*, 80% of the inventions focus on concrete printing. This is not surprising since concrete is the most basic material used in building and construction. The current research has been looking at extrusion or material jetting of concrete in a semi-liquid state to form formwork, where reinforcement steel bars are placed before concrete pouring. In addition to concrete, approximately a quarter of *materials* inventions relate to the printing of polymeric materials, such as fibre -reinforced thermoplastics. Polymeric materials confer properties such as insulation, and when co-printed with another material such as concrete, can improve properties of the printed material, including tensile strength and ductility. Co-printing of concrete-based materials with reinforcement steel bars, though highly desired by the construction industry, has remained elusive at this stage.

BREAKDOWN OF CURRENT INNOVATION INTEREST

Software – a high growth area to watch



Software has been the least explored aspect in the 3D printing arena for building and construction, covering only 7.6% of total inventions. However, the high growth rate of 46.8% in the period 2014-2018 indicates increasing interest in this aspect. In particular, scanning and modelling and building information modelling (BIM) are the major components driving this growth.

Inventions relating to the application of 3D scanning and modelling technology include repair and reconstruction of buildings and other infrastructures such as roads and railways. A specific example is Addibots' (U.S.) topography scanning, remodelling and navigation system for roadway printing using a mobile 3D printing unit.

BIM is an object-oriented building development processes that utilises multidimensional digital information, using a related set of software that enables the generation and management of digital representations of physical and functional characteristics of places. Based on patent data, BIM has been applied in the optimisation of the 3D design of a structure, resulting in improved structural properties; efficient printing workflow with minimal material wastage, real-time data collection, control and in-situ correction of a printing process, and efficient installation of complicated printed prefab. It is anticipated that the rising demand for shorter printing cycles, energy-efficient designs, and cost reductions will further propel BIM to become an important cornerstone of 3D printing technology within the industry in the future.

BREAKDOWN OF CURRENT INNOVATION INTEREST

Snapshot of innovative technologies/patents

In the course of the study, the following interesting technologies/patents in this field were observed:

- XtreeE, a French start-up founded in 2015, has been working on the integration of robotics into 3D printing through precise control of its robotic printing arm.[12] Their solution is targeted at providing a system which can maintain and supply consistent cementitious materials in a material-holding tank from a distance, to the printing site. With good control of materials properties for printing, this system enables the delivery of printing materials to a robotic arm, which houses a print-head for improved control during printing. This technology thus provides a solution to on-site bulky systems comprising both the material mixer and printing system, which complicate the printing process due to the need for design placement of the printing equipment.

  Interestingly, XtreeE has generated huge waves in the construction industry despite its young age. Regarded as one of the pioneers in 3D printing in construction, its notable projects that have captured the world's attention include the first concrete load-bearing pillar of 4 meters, a 3-meter-tall pavilion,[13] and the world's first 3D printed coral reefs.[14] These projects have allowed XtreeE to garner significant attention within the industry, where it has received investments from multiple sources, including Vinci Construction, one of the world's largest construction companies. XtreeE has been collaborating with a number of high-profile partners who are experts in the field of architecture, civil engineering, materials science, and software, including Lafarge-Holcim, ABB, and Dassault Systèmes.[15] Together, they are developing a 3D printing construction system that will not only allow for virtually limitless design opportunities, but that will help construction firms and companies cut back on both construction time and material costs.[16] More recently, Vinci Construction launched Concreative, a new subsidiary which established a 3D printing factory in Dubai for printing concrete using XtreeE's patented 3D printing technology.[17]

- Printing innovations utilising drone technology have also been observed, as a response to the issue of bulky on-site systems. Start-ups such as Whoborn Inc. (Korea)[18], DediBot (China)[19] and Braun Project Engineering GmbH (Germany)[20] have developed drones with 3D printing capability for building and construction. Although these inventions are at the concept and prototyping stage, the free-flying concept not only presents a solution to the size limitation of a static 3D printer, but also provides additional benefits such as enabling printing in confined or hard-to-reach areas, and reducing reliance on construction equipment, including scaffolds, cranes, and conveyor belts. Such drone technologies may also make it easier to print complex structures requiring fine movement control.

- In conventional 3D printing of composite materials for building and construction, 3D printing of the framework is first done before the manual overlay of steel bars/rods, then followed by the manual pouring of cement. Interestingly, new technologies detailing a one-step printing process of composite materials have emerged. Apis Cor (Russia), for example, has invented a process for extruding fibre-impregnated concrete.[21] XtreeE (France) has also developed a ductal and ultra-high performance concrete, by co-printing metallic fibre and concrete in its extrusion process.[22] With composite materials being an essential building block of infrastructures and buildings, the enablement of a single print process for infrastructures should result in reduced construction time, moving the 3D printing of buildings an inch closer to becoming a fully automated process.

BREAKDOWN OF CURRENT INNOVATION INTEREST

Snapshot of innovative technologies/patents (cont.)

While there are currently no published inventions by Singapore innovators, there is a clear interest in the usage of 3D printing for the building of infrastructures locally. For example, researchers in NUS have developed 3D-printed materials for cancelling specific noise frequencies, which can be incorporated into wall structures for sound-proofing[23]. In addition, the NUS Centre for Additive Manufacturing has launched a new Construction 3D Printing Programme, where one of its first projects involves the 3D printing of toilets.[24] Furthermore, NTU has also announced that it is working on technology for the fabrication of bathroom units using 3D printing,[25] as well as another which utilises two robots to 3D-print a concrete structure.[26]

CONCLUSION

3D printing is no longer just a niche technology for fabricating a scale model of products, but has progressively revolutionised many industries, such as aerospace, automotive, and medical technology. However, 3D printing in the building and construction industry is still relatively unexplored. The global innovation trend shows strong growth only in recent years, with lead players from the top countries of origin protecting their innovation only in their respective domestic markets. Particularly, activities relating to the deployment of 3D printing remain mostly at the proof-of-concept stage, and have not yet progressed to mass deployment. Therefore, the nascent and growing deployment of 3D printing in building infrastructure presents itself as a field with opportunities for innovators worldwide to develop new and improved technologies, including the cross-application of 3D technologies from other fields, to create breakthroughs that will transform the building and construction industry.

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